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SURVEY OF TECHNIQUES FOR CLEARING MILITARY SMOKE CLOUDS

by

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(U) A literature search and critical review on the subject of the clearing of fogs and smokes was conducted. The results, which include descriptions and evaluations of a variety of possible smoke clearing techniques, along with hundreds of citations and abstracts of articles on pertinent subjects, are presented.

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FOREWORD

At the onset of this study the author was asked to "conduct a survey of all past and present unclassified work in areas related or applicable to the clearing of military obscuration agents including, but not limited to, natural fog dispersion weather modification, condensation trail suppression, vapor and aerosol cloud dilution and dissipation, aerosol agglomeration by turbulence, electrostatic precipitation, and any other related work".

This study began one year ago with the collection of unclassified literature and information. During this time the author, a cloud physicist, was introduced to the problems related to obscuration techniques by Dr. E. Stuebing and has profited much from short visits to the laboratories at Edgewood (MD) and the facilities at China Lake (CA), where he had contact with Mr. F. Davis from the Naval Weapons Center.

With regard to this broad area, which indeed should be covered by the literary survey, the author has chosen to divide the main subject into many subareas, each having a special number. The references are sectioned so that the reader can detach them to produce his own future documentation. The key words on the quotation cards are written subjectively; however, the author has attempted to inform the reader briefly about the points from a specific article or book which are related to the goal of this study. The reader will complete many of these notes, rearrange them, and thus achieve, in the author's opinion, the mission of any literary survey: to inform the reader about the potential importance of any written document and to indicate the relationship of specific works.

The author has tried to approach the subject as broadly and as deeply as possible. In spite of his good intentions, he knows that on many points the study should be more specific and systematic and, as a matter of fact, would like to expand some areas of this study in the future. Also, he feels that there is no guideline from what point the historical notes on the subject's evolution should begin to be mentioned. The author has intentionally made several historical notes because he is convinced that in the era of data processing and huge modeling efforts, one should not forget that new ideas, even if yet not mathematically well-founded and not supported by modern and expensive technology, still can help find ways to solve new and little-known problems such as clearing of military smokes.

Josef Podzimek

Rolla, Missouri
October 8, 1978

PREFACE

The work described in this report was conducted under project/task DAAK-11-78-C-0001, entitled "Survey of Techniques for Clearing Military Smoke Clouds". It was carried out from September 1977 to September 1978.

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The author is indebted to Dr. E. Stuebing of the U. S. Army Armament Research and Development Command Research Division, Aberdeen Proving Ground, and to his staff for much valuable information. During this study the author visited Naval Weapons Center at China Lake where he had very useful discussions with Mr. F. Davis and Dr. E. E. Hindman, II and the Naval Environmental Prediction Research Facility at Monterey (Dr. A. Weinstein and A. Goroch). He is obliged to all of them for the friendly exchange of opinion and information.

Many friends and colleagues at home and abroad helped the author formulate some conclusions and collect the literature and information about rare reports and patents. He is expecially grateful to Prof. Dr. Bricard (Paris), Prof. Dr. E. Hesstvedt (Oslo), Prof. Dr. H. Hinzpeter (Hamburg), Prof. Dr. Ch. Junge (Mainz), Dr. G. Madeleine (Paris), Prof. Dr. O. Preining (Vienna), Dr. R. Reiter (Garmish-Partenkirchen), Dr. Roach (Bracknell), Dr. P. Ryder (Bracknell), Dr. R. Serpolay (Clermont-Ferrand), Prof. Dr. Schumann (Heidelberg) and Prof. Dr. R. G. Soulage (Clermont-Ferrand).

The author enjoyed very much the friendly atmosphere and the very valuable discussions with Drs. Clipson, Jarvis, and Jones at the Chemical Defense Experimental Establishment, Porton, and at the Amt für Wehrgeophysik at Traber-Trabach with Drs. Uhlig, Reiss, Aufm Kampe and others.

Drs. B. Vonnegut and J. Jiusto from the Atmospheric Sciences Research Center, SUNY at Albany, supplied the author with several rare reports and information on the extensive work in warm-fog seeding in our country.

Last but not least the author is obliged to his fellow workers, Drs. J. Schmitt and P. Yue for reviewing the narrative portion of this report and for valuable advice. Mrs. V. Maples and Mrs. C. Turek, secretaries, and Mr. G. Frick, graduate student, of the Graduate Center for Cloud Physics Research, ably supported the author in preparation of this report.

CONTENTS

SURVEY OF TECHNIQUES FOR CLEARING MILITARY SMOKE CLOUDS

1. INTRODUCTION

The problem of clearing military smokes is only briefly treated in the open literature. It has much in common with dispersion of warm fogs or clearing of industrial smoke clouds by the methodologies of increasing the visual range by droplet evaporation, removal of particulates by impaction, coagulation or scavenging. However, it has some specific features which makes the task difficult. For example, in attempting to clear a smoke cloud of highly hygroscopic substances in the free atmosphere with its large water vapor content, the heat and mass exchange will depend largely on the state of the terrain.

The clearing of military smokes above the terrain has many facets which are related to specific questions such as how large is the smoke-covered area, what is the vertical extent of the cloud, and what are the important meteorological parameters? In addition, one needs information about the physico-chemical nature of smoke particulates and about the smoke microstructure. Disregarding for the moment these specific questions, one can attempt a systematic investigation by analyzing the necessary conditions for improving the visual range in a cloud.

Visual range (ℓ) is usually calculated with the formula

$$\ell = \frac{\ln \frac{1}{\varepsilon}}{\pi n \int_0^\infty f(r) r^2 F(\frac{2\pi r}{\lambda}) dr} \qquad (1)$$

where ε is the sensitivity threshold of the sensor (for the eye $\varepsilon \equiv 0.02$), n is the total droplet concentration per cm^3 in the cloud, f(r) is the droplet size distribution function, r is the droplet radius and F is the characteristic oscillating function of the intensity of light scattered by the fog droplets and is a function of $\frac{2\pi r}{\lambda}$ where λ is the wavelength of the light. Using a mean value $\overline{r^2F}$ for the integral and the value for liquid water content of a cloud (in droplet form) $q = \frac{4}{3}\pi \rho_p n \overline{r^3}$ (ρ_p is the density of fog elements) eq. (1) can be written

$$\ell = \frac{4\rho_p \overline{r^3} \ln \frac{1}{\varepsilon}}{3q \overline{r^2 F}} . \tag{2}$$

Assuming an approximate value of F = 2.0, which is used for observations in visible light by the naked eye (ε = 0.02), the visual range for a monodispersed cloud ($\overline{n}$ = r and ρ_p = 1.0 g cm^{-3}) is

$$\ell = 3.4685\ n^{-1/3} q^{-2/3} . \tag{3}$$

All quantities are in cgs units. The droplet concentration n and the liquid water content q are quantities usually measured before an interference into the fog development is considered. In the case of a polydispersed fog (cloud) one notes that a few large drops change q considerably but make no significant change in n.

Formula (3) shows clearly that in the case of a constant light source (characterized by a specific wavelength λ) and a fixed sensor (e.g., ε = 0.02) the improvement in visibility can be achieved by decreasing the droplet concentration or by decreasing the droplet size (which affects the liquid water content q). This simple one-dimensional model requires, however, refinement if one deals with a polydispersed aerosol, i.e., the integral in the denominator of eq. (1) has to be evaluated rigorously (with a different light scattering function $F(\frac{2\pi r}{\lambda})$ for each size interval). Specifically, for a long wave light source one would need to include absorption in the treatment of the radiation transversing the fog. In addition, in the transition region between long and short wavelengths special treatment will be required.

This treatise will exclude all questions related to the improvement of visibility in fog by optical means. However, it will consider all other factors in eq. (1), including the change of droplet spectrum, which is of potential importance. These factors should be measured, calculated or estimated from a suitable model. Also, the simplified eq. (3) helps us categorize many of the laboratory experiments and field trials to be reviewed in the following chapters.

The simplest way to increase the visual range is to remove particulates by air filtration and other means. In addition, improvements in visibility can be achieved by smoke or fog cloud dilution (mixing with clear air), by droplet evaporation, by particle coagulation and by settling of large particles. Several of the methods applied in the past represent complex processes in which several elementary processes play important roles. For example, fog droplet evaporation by heating of the foggy air parcel inevitably stimulates air circulation, upward transport of fog elements, and dilution of ground fog. The treatment of fog droplets by methods which promote coagulation and fallout of particulates generates a slight downdraft. A parametrization of individual terms in equations describing complex processes is a very expedient, but often tedious task. Serious difficulties are often encountered in the specific physico-chemical nature of the smoke particles.

In enumerating the factors influencing the behavior and/or clearing of military smoke clouds, one has to stress the importance of the environment. The state of the atmosphere and of the ground may play a decisive role in fog development. However, one has the impression while reading the many reports on field experiments, that this fact has been disregarded, very often for economical reasons.

Realizing the shortness of the report and the broad field of endeavor that it must survey, the author feels that it is most useful to describe first the state of the subject based on available and unclassified articles and reports, and then to present a survey of the literature including only some key words mainly in the foreign reports to help the reader orient himself. Some of the references are without key words which means that the author has not had access to the paper or its abstract, but he thinks that it might be important for other investigators.

The state of the subject represents an interpretation of other investigators' work by the author, sometimes accompanied by simple calculations and other checking of conclusions. In the following chapters we will discuss the Physical and Chemical Properties of Military Smoke Clouds (Chapter 2), Smoke Clouds and the Environment (Chapter 3), Principles of Clearing Fog and Smoke Clouds (Chapter 4), Field Experiments (Chapter 5) and Recommendations for Future Research (Chapter 6).

2. PHYSICAL AND CHEMICAL PROPERTIES OF MILITARY SMOKE CLOUDS

By physical properties of a military fog or smoke cloud, one refers mainly to its microstructure. This includes the concentration of particulates, the size distribution, and the optical and electrical properties. Of very great importance is the physico-chemical nature of particulates: composition, surface properties, solubility and behavior in the variable humidity of the atmospheric ground layer. Many of these parameters are not well known even for the most common screening smokes or fogs.

The nature of natural fogs will be included for comparison and because one cannot exclude the influence of warm or supercooled water droplets in producing military fogs. It is well known that fogs in different localities and under different meteorological conditions have different microstructures (e.g., Mason, 1957 or Podzimek, 1959) according to collected data from different authors on the mean size of fog droplets measured on the seashore and inland. Hougton and Radford (1938) found large mean drop radii (5 to 10 μm) on the seashore and small concentrations (often below 50 cm^{-3}). Hagemann (1936) found that the mean radius of fog drops collected in Germany varied from 4.5 to 17.0 μm. Smaller mean radii of fog drops were measured by Krasikov and Chikirova (1956) in the USSR (often $r < 3$ μm). However, the latter found much larger mean radii for droplets in fogs generated by the evaporation of water from large water bodies. Very small mean radii were found in fogs in the Oslo (Norway) area ($r < 1.0$ μm).

The liquid water content of fogs has been found to be very small in comparison with clouds. Radford (1938) found values between 0.1 and 0.22 gm^{-3}. In Japan, Kuroiwa and Kinosita (1953) measured values around 0.4 gm^{-3}. Corin et al (1974) worked with new data collected in the U.S.A. These data are based on the measurements performed by Pilié (1966), Kunkel (1970) and Rogers et al (1972). Taken together, these authors found that droplet diameters are close to 10.0 μm in a radiation fog, 13.0-20.0 μm in an advection fog and 32.0 μm in a dense marine fog. However, large fluctuations in the mean droplet size, droplet concentration and liquid water content were observed. Concentration was much higher for a radiation fog (200 cm^{-3}) than for an advection fog (100-150 cm^{-3}). A dense marine fog featured an extremely low drop concentration (20-40 cm^{-3}) and relatively high liquid water content (0.5 gm^{-3}). The mean liquid water content of a radiation fog was 0.11 gm^{-3} and that of an advection fog was between 0.17 and 0.30 gm^{-3}. The thickness of a radiation fog varied from several meters to 300 m and in the case of an advection fog it was up to 600 m.

Recent measurements at a television transmitter tower in the San Francisco area (Goodman, 1976) indicated smaller mean diameters of fog droplets (4.5-8.3 μm) and concentrations ranging from 126 to 260 cm^{-3}. Due to the limited capability of the sampler in collecting large fog droplets, the measured liquid water contents in this series of measurements were much lower than those communicated by other authors (5.3×10^{-3} gm^{-3} to 6.07×10^{-2} gm^{-3}). Relatively low liquid water contents were also measured by the Calspan Corp. group in a "pure" marine fog off the coast of Nova Scotia (Mack et al, 1975). Liquid water contents ranged from 0.005 gm^{-3} (at a visibility of 5,000 m) up to 0.489 gm^{-3} (at a visibility of 50 m). At the same time the mean droplet radius varied between 4.1 to 10.7 μm.

Many of the physico-chemical properties of the military screening smokes and fogs are largely unknown, or the reports are classified and are not available to this author. However, general classification of screening smokes is found in the Thorpes Applied Dictionary of Chemistry, Vol. X, pp. 781-791.

The author (K. F. Sawyer) divides screening smokes into Carbon smokes, Oil smokes, and Hygroscopic smokes. The first kind, which is generated by an incomplete combustion of fuel oil, is now obsolete and has been superseded by other techniques which produce better screening. Oil smokes are widely used in small scale experiments (e.g., smoke generators in aerodynamic wind tunnels for tracing air motion in the boundary layer of the atmosphere, etc.) and for large area screens. The oil is usually burned with a deficiency of air and the generated smoke consists of two different components: micron sized oil droplets and larger carbon particles in the ratio 5-20 parts to 1. Better screening performance is reached by completely eliminating the carbon fraction, thus producing a white smoke which is a mixture of oil and water vapor condensation products. The mean size of particulates is between 0.5 μm and several μm. The size spectrum is relatively narrow. Large generators burn 100 gallons of oil per hour and successful screenings have been made by spraying oil into the exhaust pipes of aircraft engines.

Hygroscopic smokes have been extensively studied for several decades for their efficiency as screening smokes and due to their operational and economical advantages. The dispersed hygroscopic particulates become condensation nuclei and the ratio of the final drop mass to the initial nucleus mass (yield factor) amounts to several units depending on the environmental humidity. At humidities larger than 90% the yield factor usually surpasses 10. Phosphorus, oleum of sulfuric acid, oleum combined with chlorosulfonic acid, chlorosulfonic acid with dimethylsulfate, several metallic chlorides, "Berger Mixture" (zinc dust and carbontetrachloride with zinc and kieselguhr as absorbents) and several others of similar composition to the Berger Mixture (e.g., HCE or CTC) have been widely used. Also, several types of alkyl metal compounds are often mentioned. Some of these materials are described in monographs on particulate clouds (e.g., Green and Lane, 1957) in handbooks on applied chemistry (e.g., Green: Smoke; chapter in Hermans, 1953, 344-381), in Army manuals (e.g., TM3-215 AFM 355-7, Military Chemistry and

Chemical Agents, August 1956; TM3-300, DATM, Ground Chemical Munitions, August; NWIP 1-2 Smoke Screen Manual; NAVWEPS OP3142, Characteristic of Biological and Chemical Munitions and Delivery Systems, White Oak, Mar. US NOL, January 1963; TM 3-500 Chemical Corps Equipment Data Sheets, DA TM, Headquarters, DA, April 1961) and in several reports published from scientific meetings (e.g., ACC Symposium on Aerosols, Symp. VIII., Vol. 1, C.W.L. Spec. Publ. No. 2, July 1958, 158 pp.). Several studies and reports have been published on different aspects of the application of screening smokes of hygroscopic particles (e.g., Rodebush et al, O.S.R.D. Report No. 940, 1942; Kabrich, 1945; Axford et al, 1958; Defense Document Center for Scient. & Tech. Inform. DSA, Cameron Station, Alexandria, 1970; Rubel, 1978).

The most important factor is the dependence of the screening smoke particle size on the nature of the agent and the environmental humidity. Sawyer (1942) investigated the behavior of titanium chloride smoke which in the presence of water vapor produces a dense, stable smoke. The structure of the embryonic nuclei is largely unknown, especially at low environmental moisture. The author assumes that the stable aerosol has a composition of hydrates (presumably $TiCl_4 \cdot 5H_2O$); however, its structure changes at relative humidities higher than 50%.

A very detailed model of the growth of phosphorus smoke particles was presented recently by Rubel (1978). It is based on the "classical" approach to the description of the phosphoric acid droplet growth which includes the Kelvin and solute term and assumes equilibrium water vapor pressure between the growing droplet and its environment. The quasi-steady approach is justified by calculating the relaxation times of the growing droplets containing phosphoric acid (which holds strictly for the environment close to equilibrium on the drop growth curve). Also, the calculation of the growth rates of individual droplets seems to be justified except in the case of a highly polydisperse aerosol with a high droplet concentration. The author found a simple relationship between the size of growing phosphoric acid droplets and the environmental humidity which varied between 10% and 98%. The model phosphorus smoke was characterized by the initial radii of condensation nuclei ranging from 0.30 to 2.5 μm (0.30×10^{-15} to 0.14×10^{-12} moles). Yield factors were strongly dependent on the relative humidity so that a relative humidity of 10% corresponded to 3.89 and 90% corresponded to 16.29. This suggests a strong change in the visibility range close to the ground where the humidity gradient and its time variation are often very large.

There are not many data relating to the number of mass concentration of screening smoke particulates in the atmosphere. Usually several tens to several hundreds of particulates per cm^3 are measured shortly after the particulates reached thermal and mass growth equilibrium with the environment.

Optical properties of the fog or smoke elements represent a field of activity where many important questions remain unanswered. The situation seems to be simpler in the case of particulates with permanently homogeneous structure such as pure water droplets or metallic powders (e.g., Al) used as screening smokes. In the latter case, the nonspherical shape and the helicoidal motion of larger particulates present problems for theoretical and experimental treatment. The hygroscopic particles in the atmosphere, on the other hand, were recently investigated not only for their importance in cloud and fog forming processes, but also for their role in the propagation of light signals both in the visible and infrared domain (e.g., Junge, 1963, p. 141-146; Wells et al, 1976). Some of the most important parameters include an appropriate model size distribution of particulates and the knowledge of the influence of environmental (meteorological) factors on the deformation of the size distribution function and on the change in light scattering or extinction in the fog or smoke cloud.

Several authors prefer Junge's distribution for atmospheric aerosol (e.g., Junge, 1963, p. 118) mainly for its simplicity. For the same reason many authors have used log-normal size distribution. The gamma distribution, in its general form (e.g., Podzimek and Saad, 1974) or Deirmendjian's (e.g., Wells et al, 1976) functions also have great potential. This type of distribution seems to be very suitable for screening-smoke particle distribution in spite of the fact that during the screening smoke operation the ground layer of the atmosphere will be polluted by other particulates both soluble and insoluble in water. Different sources of pollutants and contaminants would suggest a multimode distribution rather than the single mode. Every effort should be made to establish model situations for a typical terrain and mean meteorological parameters.

The changing of the size distribution spectrum of smoke particulates is caused mainly by particle settling, coagulation and, in the case of hygroscopic nuclei, by the condensation of water vapor. Excepting the previously mentioned study of phosphorus aerosol by Rubel (1978), several investigators paid attention to the size change of atmospheric nuclei (e.g., sea salt particles) at various environmental humidities. The results of many of these studies can be applied to the clearing of screening-smoke clouds in which the smoke particles are hygroscopic. Fitzgerald (1975) found a one-to-one correspondence between "wet" and "dry" salt particle radii except in the domain of known "hysteresis" in the drop growth curve. The different behavior of the growing and diminishing salt particle could explain the findings of several authors (e.g., Podzimek, 1977) and why many of the giant sea salt nuclei exist in the form of solution drops even at a relative humidity of 55%. There is, however, a discrepancy between these findings and the statement by Sawyer (Thorpes Applied Dictionary in Chemistry, p. 783). He found that "the same quantity of water" is absorbed by a unit weight of titanium tetrachloride particles whatever the relative humidity.

The propagation of optical signals in haze, fog or smoke depends on the growth rate of particulates and is dependent on relative humidity. Attempts to calculate the visual range in fog have been made by several investigators (Dickson and Hales, 1963; Kasten, 1969, Hänel, 1968; Prishivalko and Astafyeva, 1974; Zuev et al, 1973). Hänel's study (1976) showed that the hysteresis in hygroscopic particle growth curve, and the corresponding change in the complex refractive index depend not only on the nature of a particle, but also on the whole history of particle growth. Fischer and Hänel (1972) found the real part of the index of refraction of atmospheric aerosol is between 1.55 and 1.35 and the imaginary part is between 0.047 and 0.003 for λ - 0.5 µm. Fischer (1970, 1976) concluded from his measurements that under normal atmospheric conditions one can ignore the absorption property of atmospheric aerosol for the wavelength used. An exact calculation of the refractive index was replaced later by an approximate procedure (Hänel and Dlugi, 1976) which might be useful for some of the screening smoke models.

Much attention has been paid during the last two decades to the optical properties of the aerosol particles in the infrared. Measurements of the absorptive power of atmospheric aerosol (imaginary part of the refractive index) were performed by Irving and Pollak (1968). Remsberg (1971) and Volz (1972) found that the extinction of natural aerosol has a minimum around 8 µm followed by a strong maximum near 9 µm. The same author also analyzed the optical properties of composite aerosol (e.g., incomplete dissolved salt). Several important contributions in the study of the optical properties of aqueous solutions of electrolytes in the infrared domain were made by Querry (1972), Hale and Querry (1973), Querry et al (1974) and Rhine et al (1974). The use of infrared transmitting and light scattering techniques for droplet size distribution measurement in a fog or smoke cloud seems to be promising (e.g., Eldridge, 1957, 1961, 1966).

In summary, one concludes that visible light scattering plays a much more important role in screening smokes than light absorption. For this reason detailed information about the size distribution, the composition, and eventually the shape of the particulates is necessary. In spite of the unsymmetrical distribution of the scattered light about the particle the approximation $F(\frac{2\pi r}{\lambda}) \doteq 2.0$ (see Introduction) for visible light is appropriate in many cases. A detailed investigation of the effective scattering cross section, which varies between πr^2 and $2\pi r^2$, was made by Sinclair (1947). Many physical and physiological factors, however, are involved in calculating or estimating the obscuring effect of a screening smoke might not be related to the smoke cloud microstructure, such as the color of the target, the background, etc. (e.g., Horvath and Presle, 1978). Similar problems will not be discussed in this study in spite of their great importance.

Very little has been found on the electrical charge of the generated screening smoke particles and its influence on the colloidal stability of the cloud. Sinclair (1950) reported an almost neutral nature of a homogeneous oleic acid fog produced by electric sparks. Only 5% of the particles were charged (mainly positively). However, more than 99% of the droplets can be charged by a direct current corona discharge producing droplets charged with 25 to 50 electrons. Dilution of the aerosol cloud with clean air and an increase in air humidity have no effect on the charge distribution. One expects that in the free atmosphere, electrical charges on smoke particulates will not considerably influence the colloidal stability of a smoke cloud due to the relatively high concentration of ions (>1,000 cm^3) in the ground layer over continents.

The physico-chemical properties of screening smoke particles deduced from the laboratory experiments will be quite different when investigated in the real atmosphere which is characterized by a large temperature lapse rate, by a steep gradient of humidity and by strong wind shear close to the ground. The mean values and variances of particle concentration and particle size reflect very often the turbulent nature of the atmosphere. Because the persistence or clearing of a smoke cloud is largely dependent on these elements, an analysis of the interaction of the meteorological parameters with fog or smoke is appropriate.

3. SMOKE CLOUDS AND THE ENVIRONMENT

The behavior in the environment of a military smoke cloud has much in common with natural fog. Common to both cases is the dependence on temperature field and air stability, on pressure or air parcel density (related to the pressure, temperature and substance content in a unit volume) and on the wind vector. The wind vector and its variability in space and with time represents one of the most important factors in judging the deepening or the dissipation of a fog or smoke cloud. Turbulent exchange in the boundary layer of momentum, mass and energy influences the eddy diffusion of smog or fog parcels and is closely related to the radiative transfer in the atmospheric boundary layer and to the heat exchange with the soil. However, if one attempts to change the microstructure of a smoke cloud or to clear it from the environment, several points about its behavior require special treatment.

Different, mainly in the initial stage, is the microstructure of a fog or smoke cloud (concentration, size distribution, shape and composition of particulates). Different is the interaction with atmospheric humidity (smoke particulates can be hygrophobic, insoluble in water or highly hygroscopic) and in general their physical properties are unlike (optical index of refraction, dielectric constant and surface properties). In general, smoke particles located well in interior of the cloud are less sensitive to the slight but very important changes of atmospheric parameters sufficient for natural fog creation or dissipation. One might expect that to clear military smoke would require a large amount of energy; however, it should be remembered that the smoke is concentrated in a relatively small, well defined space and is a substance of known physico-chemical properties. Different substances will require special techniques. Below will be discussed the interaction between a smoke cloud and the environment, setting aside the very different properties between a fog and a smoke cloud.

Much attention has been given during the last three decades to air pollution and to the propagation of pollutants in the atmospheric boundary layer. Of interest is the fact that a strong impulse and physical basis for the development of mathematical models came from the studies of the behavior of military smokes. The interpretation or misinterpretation of Sutton's formulas (1949, 1953) together with several important studies made the Chemical Defense Experimental Establishment at Porton in England formed a backbone for the future models. The fundamental observations and measurements in the atmospheric boundary layer were made by Lettau (1939, 1956) and Sutton (1949, 1953) and later used in several books dealing with atmospheric boundary layer as a subject of atmospheric physics (e.g., Pasquill, 1962; Pristley, 1959; Laichtman, 1970; Schmeter, 1972) or applied in an environment where pollutants propagate (e.g., Berlyand, 1975; Scorer, 1968). Besides these monographs many reports and articles on similar subjects appeared (a survey of many studies can be found in Turbulent Diffusion in Environmental Pollution, Proc. Sympos. IUTAM & IUGG, Charlottesville, Virginia, April 1973, in Advances in Geophys., Acad. Press, New York, Vol. 18 A & 18 B). Only very few of these studies, however, deal with the specific problems of fog stability and dissipation. Several articles published in the USSR (Berlyand and Onikul, 1968 a; Berlyand et al, 1968 b; Berlyand and Kurebin, 1969) and in the U.S.A. (e.g., Corrin et al, 1974) reveal the difficulties of calculating the diffusion in a calm situation or in a fog. Measurements of the diffusion at night and theoretical modeling of the diffusion of pollutants at night are still in a rudimentary stage (see for instance Deardorff, 1978). In spite of these difficulties progress has been made in investigating the behavior of a smoke or fog cloud in the boundary layer during the last three decades.

Of interest is the fact that the old measurements and theoretical investigations of air stability by Richardson (1920 a, 1920 b) are still very useful for both stable and unstable stratifications (e.g., Hanna, 1978). However, the basic value of the Richardson number Ri_o which characterizes the amplification

($Ri < Ri_o$) or damping ($Ri > Ri_o$) of a small perturbation is largely unknown. In a shear flow having a mean velocity $\bar{u}$ (z) and at a temperature lapse rate $\frac{\partial \bar{T}}{\partial Z}$ the Richardson number is a nondimensional parameter

$$Ri = \frac{g[(\frac{\partial \bar{T}}{\partial Z})_{ad} - \frac{\partial \bar{T}}{\partial Z}]}{\bar{T}\ (\partial \bar{u}/\partial z)} \ . \tag{4}$$

For instance Taylor assumes $Ri_o = 0.25$, Richardson $Ri_o = 1.00$ and Prandtl $Ri_o = 2.00$. Petterssen and Swinbank suggest $Ri_o = 0.65$ and Schlichting found that Ri_o varies between 0.029 and 0.041 which is supported by Paeschke's measurements. More experimental work and theoretical refinements will be needed before Richardson's number (Ri) will be fully applicable even for very low wind velocities and for temperature gradients far from adiabatic. Rossby and Montgomery (1935) applied in their models a mixing length

$$\ell^* = \frac{kz}{\sqrt{1 + \sigma Ri}} \tag{5}$$

where k is Karman's constant and α is a parameter which some authors found to be close to 11. A slightly different expression was found by Holzman (1943)

$$\ell^* = kz\ \sqrt{1 - \sigma_\ell Ri} \tag{6}$$

where $\sigma_\ell = 7.0$ in accordance with the measurements by Deacon (1949). However, at large temperature gradients these models, useful for the application of the mixing length hypothesis, showed a poor agreement with the measurement. An interesting investigation of a stable boundary layer was presented by Businger and Arya (1974).

The mixing length hypothesis, once so useful for a simple description of velocity field, power-law profiles and eddy viscosity ($K = \ell^{*2} \frac{\partial \bar{u}}{\partial z} \equiv \ell^* \sqrt{\overline{(w')^2}}$; w' = vertical component of turbulent velocity) assumes a new face in the statistical theory of turbulence. There the turbulent velocities (and their anisotrophy) changing with time are related to the wind shear, temperature gradient and roughness of the ground and are expressed in the form of statistical relationships valid for a certain situation and time period (e.g., Monin and Yaglom, 1973 and 1975). This approach has proven to be very useful due to the improved ability of instruments to measure the turbulent fluctuations of meteorological parameters in the boundary layer. The approach has been widely exploited in the modeling of the transport of momentum, energy and mass and has been most productive in the treatment of isotropic turbulence. However, the requirement of quasi-homogeneity and quasi-stationarity restricts the general application of many results to the boundary layer close to the ground. For this reason, Pasquill (1974) suggests dividing the polluted atmosphere into three main layers: 1) a shallow surface layer containing the pollution from nearby sources where the concentration of pollutants is strongly dependent upon heating or cooling of the surface, 2) a layer of near uniform vertical distribution of pollutants above the surface layer and 3) a "free atmosphere" containing the background pollution from distant sources or from large scale ascending motion. The statistical parameters (e.g., Lagrangian correlation coefficient $R[\zeta]$ related to the time lag ζ) will be different for each layer and are expressed in the form

$$R(\zeta) = \exp(-p\zeta)\cos(q\zeta). \tag{7}$$

From this an integral time scale can be deduced

$$t_L = \frac{p}{(p^2 + q^2)}, \tag{8}$$

which, also, enters the expression for eddy viscosity in the form

$$K_m = \sigma_w^2 t_L \doteq \frac{1}{10}\sigma_w \lambda_m \doteq \frac{1}{15}\varepsilon^{1/3}\lambda_m^{4/3}. \tag{9}$$

Where λ_m is the "equivalent wavelength" of the peak of the spectral energy curve for the w velocity component and ε is the rate of dissipation turbulent kinetic energy. σ_w is the standard deviation of the w-velocity component from its mean value. A slightly different numerical factor was used by Hanna (1978) for eddy diffusivity: $K_z = 0.15\ \sigma_w\ \lambda_m$. Much attention has been given recently to the variation of the eddy viscosity and diffusivity with the altitude and with stability conditions (e.g., Pasquill, 1974; Hanna, 1978). Pasquill published the dependence of K_m on altitude z for stable, neutral and unstable conditions. Hanna mentioned an expression for K_z valid for the surface layer:

$$K_z = 0.35\ u_x\ [z/\phi_h\ (z/L)] \qquad (10)$$

where u_x is the friction speed, L is the Monin-Obukhov length and ϕ_h is a universal function of z/L which was empirically deduced. For unstable conditions

$$\phi_h\ (z/L) = 0.74\ (1-9\ z/L)^{-1/2} \qquad (11a)$$

and for stable stratification

$$\phi_h\ (z/L) = 0.74 + 4.7\ z/L \qquad (11b)$$

is recommended. Kaimal et al (1976) deduced formulas where λ_m is a function of z/L

$$\lambda_{m_1} = \frac{z}{0.55 - 0.38\ z/L} \qquad 0 < z < /L/ \qquad (12)$$

$$\lambda_{m_2} = 5.9\ z \qquad /L/ < z < 0.1\ h \qquad (13)$$

$$\lambda_{m_3} = 1.5\ h\ [1 - \exp\ (-5\ z/h)] \qquad 0.1\ h < z < h. \qquad (14)$$

The usefulness of similar formulas has to be checked in the future, but the importance of the measurement of the vertical components of turbulent velocity and of the turbulent energy spectrum is apparent. Recent measurements in different parts of the U.S.A. (Hanna, 1978) show already that the depth of the mixed layer h is an important factor which changes during the daytime and when combined with the surface heat flux Q determines the scaling velocity $w_x = (Qh)^{1/3}$. Scaling velocity w_x

and the depth h determine the state of the boundary layer. These new findings in boundary layer theory influence the diffusion model of propagation of pollutants or smoke particles. Very beneficial would be the knowledge of some of the microstructural characteristics of the smoke. That information, combined with the features of the terrain, could lead to a useful forecast of the smoke behavior or prediction of its clearing. Very often mesoscale meteorological processes will considerably influence smoke microstructure (solar radiation, washout and fallout). Some advice on these interactions can be found in manuals for forecasting air pollution (e.g., WMO Technical Note No. 121).

Still unresolved are basic problems to the general application of the statistical theory of turbulence to the diffusion of pollutants and to the exchange in the boundary layer. Shortcomings of the gradient transport models in turbulence were discussed several years ago by Corrsin (1976) from the point of view of random walk. The largest error seems to be related to the inhomogeneities produced by the transporting mechanisms (scale of turbulence and rms velocity).

There are basic difficulties in modeling air pollution from sources scattered over a large territory because of the different density and intensity of sources and their orientation with regard to the wind direction and velocity. The classical (formal) approach was to use a dense grid and to calculate for each point the concentration corresponding to main air trajectories (Berlyand, 1972).

Special treatment is required for the case of anomalous variation of wind-velocity with height mainly for an elevated temperature inversion and the dispersion of smoke particulates in calm-wind conditions. Berlyand (1972) made several attempts to describe similar anomalous propagation of pollutants with the aid of empirical relationships and dimensional analysis. However, the general validity of similar calculations is very limited. Several authors dealt with the propagation of pollutants over an uneven terrain. In this case a new z-coordinate was usually introduced $z' = z - h(x)$ enabling one to describe the shape of the terrain (Berlyand, 1972). Berlyand et al (1968 b) used the so called potential current method with a complex argument which permitted conformal representation on the semiplane with curvilinear boundary. This method was previously used by Stümke (1964, 1966) who, however, used constant coefficients in the diffusion equation.

Another case requiring special treatment is that of atmospheric diffusion in fog or a smoke cloud and the interaction of smoke (fog) elements with the environment. Pollutants (gases, particulates) are absorbed or deposited on smoke (fog) particles, the particle size is largely dependent on water vapor transport and on droplet coagulation efficiency. On the other hand, all parameters are dependent on the turbulent fluctuations of the individual parameters. Unfortunately, very few measurements have been made in this area. Typical data measured in fogs (Corrin et al, 1976) are: Shear of the mean wind $\frac{\partial \overline{v}}{\partial z} = 0$ to $0.015\ s^{-1}$, turbulent transport coefficient $K_m \doteq 0.1 - 10^2 m^2 s^{-1}$ and the cooling rate for fog $\frac{\partial T}{\partial z} \doteq 1 - 3°C\ hr^{-1}$. Very little information is available about the turbulent intensity measured in a fog or smoke cloud for a well defined meteorological situation. Sedunov (1972, p. 92) assumed a situation in a layer type cloud with a mean updraft velocity of $\overline{w} = 1 - 3$ cm sec^{-1} and estimated the influence of fluctuating velocity $[\overline{(w')^2}]^{1/2} \doteq 30 - 50$ cm sec^{-1} on the activation of hygroscopic and insoluble nuclei. For salt solution nuclei containing 20% of solute by weight he found that the nuclei activation rate was 4 sec^{-1} cm^{-3} compared to 10^{-3} sec^{-1} cm^{-3} for insoluble nuclei. In both cases Junge's distribution of nuclei was assumed.

New perspectives are opened in the author's opinion, by the stochastic condensation theory. However, the mathematical framework of this theory is still in the rudimentary stage (e.g., Sedunov, 1972; Clark and Hall, 1978). Clark and Hall calculated e.g., the droplet size distribution from the equations including the perturbation terms under the more general three-dimensional "deformation" term and assuming a non-varying dissipation of turbulent energy $\varepsilon = -100\ cm^2\ sec^{-3}$ corresponding to the values

$[\overline{(u')^2}]^{1/2} \doteq [\overline{(v')^2}]^{1/2} = 46.6$ and $[\overline{(w')^2}]^{1/2} = 69.1$ cm sec^{-1}.

Another question which arises is how the microturbulence or the fluctuations of microstructural parameters in the fog influence the coagulation of fog droplets or smoke particulates. In a layer-type cloud Staffman and Turner (1956) found an insignificant effect due to small scale turbulence. However, Woods et al (1972) and Jonas (1972) indicate that even normal shear in the velocity field might contribute significantly to droplet collision (experiments by Jonas and Goldsmith at shear greater than 7 sec^{-1}). In essence, this conclusion was supported by Tennekes and Woods (1973). The main problem is still the lack of systematic measurements of meteorological parameters inside of a fog close to the ground.

Finally, it should be emphasized that the interaction of the environment with a fog or smoke cloud is an extremely complex process. Successful clearing of military smoke requires a rapid estimate of the smoke extent, and its nature, and may require a very fast measurement of the main meteorological elements such as wind speed and direction, temperature and lapse rate, humidity, visibility and possibly solar radiation.

4. PRINCIPLES OF CLEARING FOG AND SMOKE CLOUDS

This survey of methods for clearing fog and smoke clouds will be based mainly on the methodology developed for clearing natural fogs. The reason is first, not many of the methods for clearing smoke clouds have been described in the open literature and second, many of the principles applied to natural fogs are suitable for clearing of smoke clouds.

Categorization by different techniques for natural fog dispersion has been made by several authors (e.g., Katchurin, 1973). In the author's opinion, the most suitable seems to be divisions based on the main physical processes leading to the improvement of visibility in a smoke cloud. In this survey all methods for changing the optical parameters of the light scattering elements and the freezing of liquid elements will be omitted.

The following scheme is suggested:

Direct removal of smog and fog particles from the cloud by: a) filtration, b) sedimentation, c) phoretic forces, and d) condensation of vapors on nuclei.

Coagulation and subsequent sedimentation in: a) a gravitational field, b) an electric field, and c) air acoustic field.

Evaporation of droplets through: a) heating of the fog (FIDO), b) combination of thermal and dynamical system (TURBOCLAIR), c) mixing with dry air (dynamical method), d) absorption of solar radiation, and e) heating of the foggy air by laser beam.

Dilution of the aerosol cloud through: a) mixing with clean air in horizontal direction, and b) mixing or particle transport through artificial convection.

Other techniques.

In the following the principles of different techniques will be discussed and some estimates of their importance, based on information in the available literature, will be mentioned.

4.1 Direct Removal of Smog and Fog Particles

4.1.1 Filtration - The simplest method to remove the smog or fog particles from the air is the direct deposition of particulates onto "eliminators". Devi[illegible] of this type consist of fine wire meshes or air deflectors on which the foggy air is cleaned by the higher kinetic energy of the droplets in comparison to the air parcel. Patents have been issued for the clearing of fog by blowing it through a set of fine rotating meshes (West German Pat. 1135940, U. Smieschek), by depositing fog drops on deflectors (West German Pat. 1816733, U. Regehr) and by towing large fine meshes behind a vehicle along the runways or highways (West German Pat. 1909946, K. Wanders). A large number of similar devices have been suggested in the U.S.A. and many other countries. However, the main problem seems to be the resistance to the passage of air through the mesh or deflector. It has been estimated that 2,000 m^3 of air has to be moved through the system per second (Hougton and Radford, 1938) for it to be effective Also, most of the authors do not consider that in the case of water drops the liquid or humidity must be removed from the collector. For this reason, several inventors have suggested the removal of fog droplets by cooling them down below the freezing point in a system of jalousie-type deflectors (Austrian Pat. 166780, E. J. Millonig). One also notes that the efficiency of mechanical separation of smoke particulates can be increased by the incorporation of electrostatic filters (e.g., Austrian Pat. 305548, Braun Aktien-Ges., Frankfurt a. M.).

The physical principles of the direct deposition of particulates on bodies of simple geometry are well known and a large number of experiments on the filtration efficiency of different materials have been described (e.g., books by Davies, 1973; Davies, 1966, Fuchs, 1959). The practical disadvantages of applying this method for field operations probably caused the very pesimistic statement by Hougton and Radford (1938, p. 20): "It must be concluded that although possible, the method is hardly applicable". However, this statement was not fully supported by Prof. C. Junge during a private discussion with the author. He believes that for small area fog clearing experiments (such as were anticipated by one of the German inventors) this method should not be rejected without careful checking of its potential. The author of this report feels that this might also be true with regard to clearing military smokes obscuring small areas.

4.1.2 Sedimentation - A spherical particle 0.5 μm in diameter and of unit density will settle in the atmosphere under calm wind conditions at a rate of 6.8×10^{-4} cm sec^{-1}. The settling rate of a 5.0 μm particle will be 5.0×10^{-2} cm sec^{-1}. This low settling rate can, however, be strongly influenced by air turbulence in the ground layer and by the air advection. The type of vegetation combined with the air turbulence plays a decisive role in smoke particle deposition above the ground. This was clearly demonstrated by the deposition of marine fog droplets on the leaves of shrubs and trees (Oura and Hori, 1953) which generate an intense turbulent field in their wake. Another interesting observation was made by Eichborn (1954) who observed that the average behavior of aerosol particles above the terrain is related to the time of day and to the solar radiation. He found the sinking velocity of smoke particles in the early morning sunshine was 15 to 20 times greater than in cloudy weather or at evening dusk.

Magono et al (1964) undertook with his fellow workers a very interesting attempt at fog dispersion using the downward air flow caused by the fall of water drops released from a helicopter 100 m above the fog layer. The size of water drops which fell through the fog was selected carefully to attain the maximum entrainment of the particulates in the wake of following larger drops. The author of this report suggests that the use of dry ice particles of several mm in diameter might enhance the transport of smoke aerosol toward the ground. The wake effect might be magnified in this case by the larger density of gaseous CO_2.

The main importance of sedimentation processes is attributed, however, to the increase of the settling rate of particulates by condensation of vapors. This will be discussed later.

4.1.3 Phoretic Forces - Under phoretic forces one lists diffusiophoretic (a special case is Stefan flow), thermophoretic, photophoretic and electrophoretic forces. Descriptions of the mechanisms and estimates of the importance of individual cases have been published, e.g., in the Davies book on Aerosol Science (1966), by Hidy and Brock (1970), by Fuchs (1959) and others. For application to clearing of military smokes one has to consider two basic cases: 1) particles are collected in a high gradient of a diffusing substance, a temperature gradient or electric potential in a device which serves as a precipitation zone through which the medium is passing, or 2) the high diffusive gradients promoting the smoke particle deposition are generated around droplets which are growing by vapor condensation process (or serving as heat sink).

As early as 1870 Tyndal discovered that aerosol particles move towards a body with a lower temperature and in 1887 Stefan found that there is a "dust-free" zone around an evaporating body. Since that time very few investigators have paid attention to this phenomenon. However, Stetter (1954) obtained a patent for an arrangement whereby dust particles can be deposited in a concentration--or temperature gradient. Facy (1955) described a "dust-free" zone around an evaporating drop. The theoretical explanation of the observed features started independently in West Germany (the papers by Waldmann and Schmidt are reviewed in Davies, 1966) and in the USSR. The Russian group headed by Deryaguin published their results in several papers (Deryaguin and Bakanov, 1957; Bakanov and Deryaguin, 1959; Dukhin and Deryaguin, 1964; Deryaguin and Yalamov, 1971, and Deryaguin et al, 1971). The most important result of these studies was the difference of particle deposition rates for ultrafine particulates (Molecular regime) and for low Kn numbers. The other important finding is the difference in deposition velocity between a moderately large volatile aerosol particle and nonvolatile particle (Deryaguin and Yalamov, 1971; Deryaguin et al, 1971). Schmidt's and later Goldsmith's experiments (Davies, 1966) showed a reasonable agreement with the theories predicted. The data indicate also the small deposition rate of the particles subjected to the phoretical forces. Only in exceptional cases can one find a situation, when the phoretical deposition might not be negligible in the atmosphere (e.g., in mixed clouds as mentioned by Podzimek, 1965 and 1966 and during the special case of particle scavenging reported by Slinn, 1976 and 1968).

Further development of the theory of diffusiophoretical forces covers the important transitional regime of particle sizes (e.g., Brock, 1968 or Annis et al, 1973). However, a rough calculation of the deposition velocity of particulates according to Goldsmith's formula (Davies, 1966) given for diffusiophoresis

$$v_d = -1.9 \cdot 10^{-4} \frac{dp}{dx} \text{ [cm sec}^{-1}\text{]} \tag{15}$$

(p is the pressure in mb) or for thermophoresis

$$v_T = -\frac{A}{T}\frac{dT}{dx}\ [\mathrm{cm\ sec^{-1}}] \ . \qquad (16)$$

Note how small the deposition rates are if one considers the gradients existing in the atmosphere and if one assumes particules smaller than 0.1 μm. For larger particulates one has to include a correction term. The formulas are based, however, on a quasi-steady situation around a growing or dimishing droplet which might not be applicable if the collector's size is changing rapidly. The influence of a fast growing collector should be investigated in more detail before a final judgement about the importance of diffusiophoretic forces for the clearing of military smoke is made.

In accordance with some preliminary calculations of the influence of photophoretical forces on particle deposition one concludes that they are unimportant for the clearing of a fog or smoke cloud. For this estimate the author took the formulas published by Preining in Davies' book (1966) and assumed that a fog is irradiated by a source of light or laser beam of medium intensity. The collision increase among the droplets of 0.5 and 5.0 μm size is not significant. However, there is still great uncertainty in the appropriateness of the formulas for photophoretic forces.

The electrophoretic case will be discussed later in connection with electrostatic coagulation and electrical charging of particulates. Strong limitations are imposed to the attempts to reach a very high potential gradient in the atmosphere close to the ground. Usually corona discharge above uneven terrain covered with vegetation makes the high charging of individual particles impossible (private communication by Vonnegut).

<u>4.1.4 Condensation of Vapors on Nuclei</u> - Basically one can divide the physical processes used for clearing of fogs into two large groups: Those operating at positive temperatures (°C) and those applied at negative or freezing temperatures (below 0°C). The first division uses mainly the condensational growth of some

(usually highly hygroscopic) substances, the second uses direct water vapor transport from supercooled water droplets onto ice crystals (desublimation) or first enhances the freezing of supercooled droplets by contact nucleation followed by sublimation or coagulation process. This paragraph will discuss the first process and only some of the basic ideas pertaining to the second one.

Nucleation on hygroscopic nuclei with the resulting droplet growth has been discussed in many textbooks on cloud physics and physical chemistry. Several interesting points related to the application of the theory for clearing of natural fogs have been made by Corrin et al (1974), and nucleation and droplet growth on phosphorus smoke particles has been treated recently by Rubel (1978).

Hygroscopic condensation nuclei such as NaCl, $CaCl_2$, NH_4Cl or droplets of solutions of H_2SO_4 or H_3PO_4 are treated in the same way as far as the progressive stages of growth are concerned. They act, however, differently in the early stage of nucleation. One usually assumes the validity of Raoult's law for the whole process of growing droplets, and one calculates the equilibrium size of a solution droplet related to the environmental humidity. A very challenging problem for a given nucleus is to calculate the characteristic relaxation time needed to reach an equilibrium state at a given humidity. This question has been analyzed in detail by Sedunov (1972), be Carstens et al (1974) and for a phosphoric acid droplet by Rubel (1978). Rubel used an accommodation coefficient $\alpha = 1.0$ and a condensation coefficient $\beta = 0.5$. He found relaxation times between 10^{-3} to 0.9 seconds for nuclei sizes corresponding to those generated in phosphorus smokes and for relative humidities ranging from 10% to 98%. Larger values of relaxation time were obtained by Carstens for NaCl nuclei with a condensation coefficient $\beta = 0.035$. In spite of the open question of the value of the condensation coefficient it seems reasonable to assume quasi-steady state for the model calculations.

With regard to the relationship between the smoke cloud or fog microstructure and visibility mentioned in the Introduction, one concludes that seeding with hygroscopic substances will contribute to the colloidal instability of a system. A few of the large drops will grow at the expense of the many tiny droplets. This effect combined with several changes of the surface properties of the seeded drops and possibly combined with electrical charge redistribution may contribute to the enhancement of coagulation, faster drop growth and finally fallout of the large drops. The visual range in a seeded fog is, however, strongly dependent not only on the droplet concentration but also on the droplet size spectrum as a function of time (Saad et al, 1976).

In most of the studies outlining the methodology for hygroscopic nuclei seeding ($NaCl$, $CaCl_2$) the authors (e.g., Hougton and Radford, 1938; Stewart, 1958; Jiusto, 1964 a, 1964 b; Jiusto et al, 1968; Kocmond et al, 1968; Kocmond and Jiusto, 1968; Kocmond and Pilié, 1969; Pilié, 1969; Kraght, 1969; Kornfeld, 1970; Fedoseev, 1971; Serpolay and Andro, 1972) concluded that the amount of salt used for a successful experiment is not very large. Hougton and Radford's calculation led to a spraying rate of 4 to 5 liters of saturated solution ($CaCl_2$) per second. Cornell Laboratory (Calspan) experiments indicated that 1.6 mg of dry NaCl per m^3 might cause a substantial improvement in visibility in a dense fog (Fig. 1). The recommended particle sizes for NaCl crystals varied between 5 to 35 μm and the perceivable effect was observed one to several minutes after the seeding. Katchurin (1973) reports a substantial improvement of the visibility in a large expansion chamber three minutes after seeding the fog with hygroscopic nuclei of 1 to 5 μm in size. The improved visibility lasted more than ten minutes after the introduction of the seeding agent (NaCl). During systematic experiments it was found that the change in humidity in the 600 m^3 chamber was usually smaller than 1% R.H. (Jiusto et al, 1968), nevertheless it led to the evaporation of a large portion of droplets. The effect of seeding in nature is not always as satisfactory as it is in the laboratory. The only explanation is that air mass exchange with the soil, cannot be simulated successfully in a chamber. The results of some of the field experiments with hygroscopic substances will be discussed later.

Several other substances enhancing condensation of water vapor have been mentioned such as the mixture of HCl SO_3 and SO_3 (McDonald et al, 1965), certain phosphates and polyelectrolytes (Kocmond, 1968). The latter substances (e.g., polyacrylamines) can swell enormously with the liquid water and a high electric charge density on their surface could contribute to a fast coagulation with other droplets and to the fast removal of drops from the foggy air. However, preliminary tests of polyelectrolytes on artificial fog clearing are not very encouraging (Kocmond, 1969). Other active substances for warm-fog seeding have been investigated by Hindman and Clark (1972).

Warm-fog dispersal tests with glycerine did not yield conclusive results (McDuff et al, 1973 a, b, c) and the use of urea (Weinstein and Silverman, 1973) for the combination of urea-bentonite (Depietri and Rosini, 1968) is still in rudimentary stage. The use of water-absorbing ion-exchanging resins for fog dispersion in the USSR was not recommended after the laboratory experiments by Chikirova (1967) were completed. Some positive effect was found using a powder of an alginic acid as a warm-fog-seeding agent (Paugam and Serpolay, 1970; Maguet and Serpolay, 1973). The noncorrosive sodium alginate powder is comparable with NaCl crystals as far as the activation threshold is concerned.

Another means to support the colloidal instability of a warm fog is to use substances which are effective in preventing the growth of drops. The idea of covering some droplets by surfactants in order to enhance the growth of the uncovered ones is, in the author's opinion, not yet well supported by theoretical analysis (Deryaguin et al, 1960; Deryaguin and Durgin, 1969; Deryaguin et al, 1971; Podzimek and Saad, 1975) and Shiniaiev, 1968; Bigg et al, 1969; Leonov et al, 1969, Bakhanova et al, 1969; Leonov and Prokhorov, 1967; Storozhilova, 1971; Kocmond et al, 1971, and Duguin and Stampfer, 1971) which are inconclusive. The possible effect of surface active substances on droplet coagulation will be discussed later in more

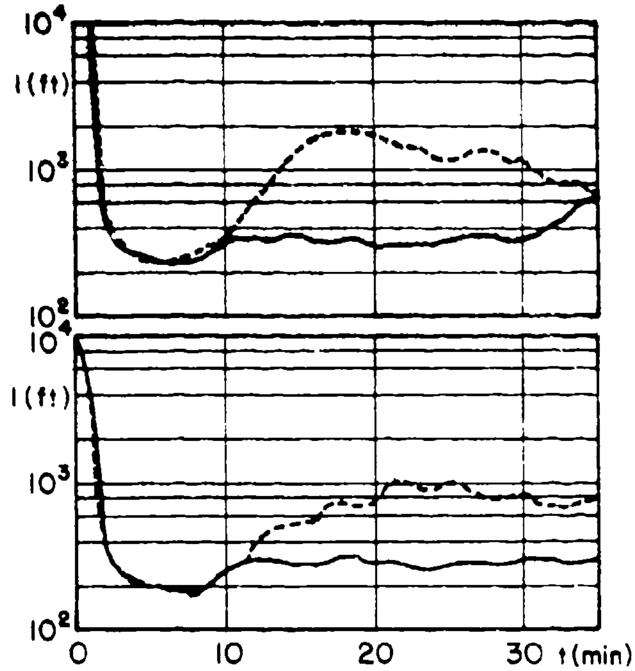

Fig. 1. Visibility ℓ [ft.] in an artificial fog as a function of time t [min.]. Dashed curve is for the fog seeded with salt nuclei in a concentration of 8 mg m^{-3}, solid curve corresponds to the control expansion (without seeding). The upper figure was obtained from measurements at 15 ft. level and the lower curves were plotted from the measurements above the bottom of the expansion chamber. Jiusto, et al (1968)

detail. It appears that most of the authors support the idea that the growth of a nucleus or a drop covered by surfactant is only retarded by the surfactant layer and that after several minutes the drop will reach the size of a drop which was not covered by any surface active material. This result, however, is influenced greatly by the theoretical model which is usually a quasi-steady approach with the assumption of a time-independent diffusion coefficient. Also, the structural differences of different surfactants some of which are soluble and some insoluble in water should be stressed more in the author's opinion.

The conclusion one draws for the clearing of military smoke clouds from the warm-fog-seeding experiments is the following: very useful relationships for the hygroscopic nuclei and solution drop growth, applicable to atmospheric conditions, have been obtained. However, a wide exploitation of the hygroscopic nuclei seeding technique cannot be anticipated if it is not combined with other mechanisms such as coalescence or phoretical forces. This is because military smokes consist mainly of highly hygroscopic substances. In the case of fine solid smoke particles some chance exists for removal of them by hygroscopic particle seeding. The author favorably considers the possibility that one can use some surfactants to cover part of the population of the smoke particles (composed of highly hygroscopic substances) in order to reach colloidal instability. However, a new theoretical approach to this problem has to be developed and systematic experiments mainly with insoluble surfactants will be needed (Fig. 2).

The growth of ice crystals among supercooled water droplets is very similar to the transfer of water vapor onto salt solution droplets. The gradient of water vapor around the crystals is maintained by the difference of vapor pressure over water and ice which is maximum about -12°C. Without going into many details one might note (aims with the possible importance of a similar process in clearing military smokes) the fact that in water vapor gradient particulates of insoluble and soluble

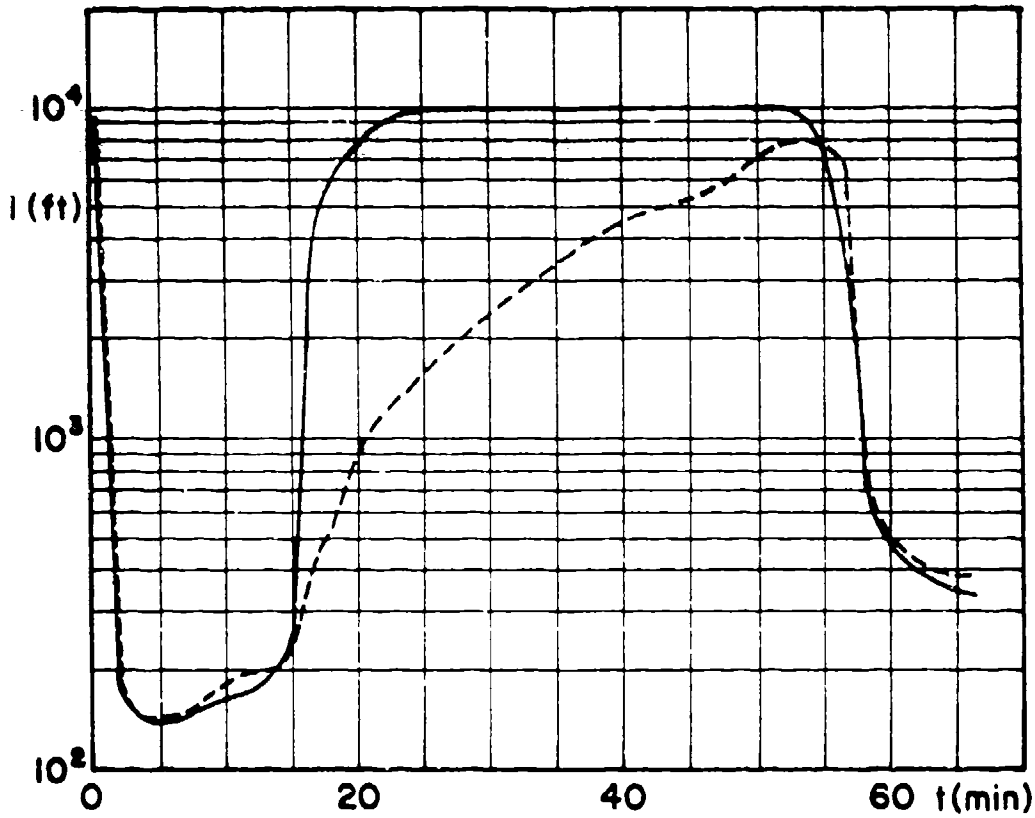

Fig. 2. Visibility ℓ [ft.] as a function of time t [min.] for a control fog (full line) and for a fog seeded with 0.9 g of cetyl alcohol (dashed line). Kocmond, et al (1972).

substances are transported toward ice crystals (Stefan flow).

The model of water phase transition in a supercooled fog uses the equation for water vapor balance inside of the fog, the growth rate of the ice crystal and evaporation of water drops (e.g., Katchurin, 1973). From these equations three unknowns (air humidity, size of the crystal and of the drops) can be calculated as a function of time. Due to the number of evaporating drops and large crystals which settle rapidly the visibility of fog can considerably increase within 10 to 20 minutes depending on the concentration of ice nuclei or nucleating agent. The main problem is to seed enough but not to overseed the supercooled fog.

Several techniques have been introduced in field experiments with the aim of transforming the supercooled fog into ice fog (with better visibility). The most successful is dry ice seeding, used as early as 1931 by Veraart. Another technique is the dispersion of liquid propane and the use of substances with a high ice nucleating capability (AgI, PbI_2, CuS, metaldehyde).

Supercooled fog seeding by dry ice was successfully performed by many authors, e.g., by Aufm Kampe et al (1957), Gaivoronskii and Seregin (1962), Gaivoronskii et al (1965), Beliaiev et al (1966), Rabbe (1969), Müller (1974), etc. An analysis of the physical processes related to dry ice seeding was performed by Hindman (1966), Rabbe et al (1968) and Buikov and Polovina (1969).

Several experiments with liquid propane spraying were performed in France (e.g., Olivier, 1956; Serpolay, 1959; Cot and Serpolay, 1961; Serpolay 1969; Andro and Serpolay, 1970), in the U.S.A. (Gerdel, 1968; Kumai, 1969; Wise, 1975) and in other countries. A detailed analysis of the physical processes related to the clearing of supercooled fogs by liquid propane spraying has been made by Charry and Lininger (1975).

Since 1947 when Vonnegut introduced silver iodide into cloud physics as an ice nucleating agent, many investigators have applied it in supercooled fog seeding experiments. Surveys of the physico-chemical properties of AgI can be found in any modern textbook on cloud physics. Balabanova (1960) showed that silver iodide acts mainly through contact nucleation in a supercooled fog because the number of generated ice crystals increased only to a definite maximum concentration which is related to the number of supercooled droplets. Several experiments with silver iodide fog seeding were performed by Müller (1960), Nikandrov (1962) and Sumin (1968). The latter analyzed the capability of AgI and PbI_2 to convert a supercooled fog into an ice fog and found a relationship between the rate of crystallization, the temperature, the wind-speed and the propagation of the crystallization zone. The same author later published (Sumin, 1969) a similar study on the use of CuS particles as ice nuclei. Relatively few field applications are found for seeding with metaldehyde (Fukuta, 1969).

In general, the seeding of supercooled fogs is one of the few fields in which cloud physicists gained an economically significant success. However, in the author's opinion, the potential use of similar techniques for clearing of military smokes is very limited except in the case where ice crystals are generated having articulated forms and thus have much larger scavenging efficiency than water drops.

4.2 Coagulation

4.2.1 Gravitational Coagulation (Scavenging)

- In the early thirties the group headed by Wigand started to investigate the stability of fogs and the droplet coagulation in a gravitational field (Wigand and Frankenberger, 1930; Wigand, 1930; Frankenberger, 1930, Findeisen, 1930). It was found that the fog droplet size spectrum in a large chamber changes with time and that the coagulation of drops accelerates their growth and their removal through settling.

Most of the important studies on gravitational coagulation have been published after the memorable publication of Langmuir's investigation into the collision efficiency of two falling droplets (Langmuir, 1948). They are treated in full details in the textbooks on cloud physics. For this reason, only few remarks on this subject will be made.

Neiburger et al (1974) summarized the findings of many authors who calculated and measured the collision efficiency of falling drops. He tried to explain the discrepancy in collision efficiency for equally sized drops calculated by an analytical formula and by the formula deduced by Shafrir and Neiburger which postulates a zero collision efficiency for droplets of 30 μm in size. A similar result obtained originally by Hocking (1959), was later corrected (Hocking and Jonas, 1970) and challenged by Klett and Davis (1973), Lin and Lee (1975), de Almeida (1977) and others. Experimental verification of the theoretical results was attempted by Woods and Mason (1965), Beard and Pruppacher (1968), Abboth (1974) for drops of similar size and by Beard and Pruppacher (1971), Tung and Beard (1978) for dissimilar drops. The results show a good agreement with the theoretical values of collision efficiencies, at least for the drop size ratios $p < 0.1$ and $0.7 < p < 1.0$. The lowest range is the most important domain for smoke particle scavenging studies.

The conclusions from the theoretical and experimental studies of gravitational coagulation were applied in simple models of raindrop scavenging of the tropospheric aerosol and in experimental studies. Several articles of this nature were published in the proceedings of the symposiums on Precipitation Scavenging (e.g., Dana, 1970; Adam and Semonin, 1970; McCormack and Hilliard, 1970). Experimental verification on the theoretical models of raindrop scavenging efficiencies for submicron particles was performed also by McCully et al (1956), Barth (1959), Severynse (1963), by Starr and Mason (1966), Hagen (1967) and others. The very interesting change in catching efficiency of droplets for micron size aerosol particles around Re ≐ 250 was explained by the change of the shape of the wake formed behind spherical drops (Toulcova and Podzimek, 1968).

Facy (1960), Podzimek (1966) and Sood and Jackson (1969) called attention to the potentially important scavenging of particulates by falling snow crystals. There is, however, a large scatter of collection efficiencies deduced from experiments by different authors. In spite of the low catching efficiency of ice crystals in scavenging particulates of 1.0 to 3.4 μm in size (according to Sood and Jackson 1 to 4%) the importance of this process is obvious. The most important is the fact that on stellar type ice crystals Podzimek (1970) found droplets as small as 0.5 μm in size and that motion of ice crystals (e.g., Podzimek, 1967) greatly enhances their catching efficiency. The highest efficiency was seen for dendritic ice crystals (also due to their slow, oscillatory motion) and rimed ice crystals. The laboratory study by Yue and Podzimek (1975) of the catching efficiency of the crystals of simple forms and its comparison with the experiments by Sasyo (1971) and theoretical calculations by Pitter et al (1973) indicate a potential use of this technique for clearing of military smokes.

In the author's opinion this simple technique can use any collectors with fine crystallinic structure and high catching efficiency. The crystals can be artificially generated and used at positive temperatures in a smoke cloud. Also, it would be worthwhile to investigate theoretically and experimentally the stability of motion of crystal collectors and their aggregates.

4.2.2 Coagulation Due to Electric Forces - One of the first attempts to influence the evolution of a fog is described in the article by Van de Vyver (1901). More systematic studies were undertaken by Wigand (1926) and Wigand and Frankenberger (1931) with the aim to stabilize or to disperse the fog. Wigand also obtained a German patent on a procedure for fog dispersion by using unipolarly charged droplets.

In the following years two techniques were developed for fog dispersion based on enhanced coagulation due to highly charged individual collectors (drops) or due to induced charges on drops in a strong electric field. The first technique was supported mainly by the theoretical study by Pauthenier and Cochet (1953) who considered a positively charged drop among its neighboring cloud drops. Usually in nature many drops bear charges amounting to several tens to several hundred elementary charged. Introduction of unipolarly charged particles or bipolarly charged particles into a fog might enhance the coagulation postulated by Wigand. Vadell (1961) undertook laboratory experiments in the dispersion of fogs. He came to the conclusion that bipolarly charged drops had less effect on drop coagulation than unipolarly charged ones. Sedimentation and droplet motion in a steady and turbulent field present a problem which has been partly solved in the past few decades in the laboratory and by theoretical calculations (e.g., Semonin and Plumlee, 1966; Neiburger et al, 1974; Schlamp et al, 1976 and 1978).

One postulates artifical collectors immobile or falling through oppositely charged smoke or fog elements. Assuming a collector with radius 10^{-2} cm, with a charge corresponding to a potential difference of 10,000 V and with a downward velocity of 100 cm sec^{-1} in a fog with drops of radius 2.0 μm and 200 elementary charges on each, a simple calculation shows that the collection efficiency of the charged system is approximately 15 times larger than that of an uncharged one. This simple consideration clearly shows that electrical charging can significantly enhance the coagulation or removal of fog droplets. However, other factors such as air stability and uneveness of the terrain greatly limit the applicability of these results in the field. The mechanism of effective droplet or aerosol charging as a result of capture of gas ions has been described by Natanson (1960). Carroz and Keller (1976) later describe the charging of sprayed water drops by corona and induction. Practical applications of these calculations in the field and in the laboratory were made by Wigand (1931) and Vadell (1961). Recently a new technique of using charged bubbles (electrogasdynamic method) as collectors was reported by Wright and Clark (1973) and by Chiang et al (1975). However, the preliminary results are inconclusive.

Physical description of particle precipitation in a strong electric field are found in most of the books on electrostatic precipitation (e.g., White, 1963). To the author's knowledge, the most comprehensive study on this subject was performed by A. D. Little's research group and described by Vonnegut (Little, 1953, 1954, 1955, 1956 and 1965). In a series of papers they reported their investigations on dispersion of warm-fogs (especially using an electric field). The investigators performed laboratory and field experiments with a "Fine-wire space-charge generator" (800 ft. long and 0.005 inch in diameter stainless steel wire) placed on poles 12 ft. high above the ground. The wire was maintained at either positive or negative polarity at potentials up to 35 kV. The electric field was 10 to 20 V cm^{-1} which appeared to be insufficient for any noticeable precipitation of fog droplets. During a private discussion, Dr. Vonnegut expressed the opinion that the main problem, due to corona charge losses, is to maintain the high potential difference above the uneven ground. Different aspects of electrostatic fog precipitation are mentioned in the article by Phan-Cong and Jordan (1969). Furthermore, the rather pessimistic outlook for electrostatic fog precipitation is supported by Tag (1974) who performed a numerical simulation of warm-fog dissipation by electrically enhanced coallescence under conditions corresponding to a real situation in the Panama-Canal zone. He found that only an electric field as high as 3,000 V cm^{-1} might cause a significant improvement in visibility. However, this result contradicts a more optimistic conclusion by Katchurin (1973) who used a very simplified one-dimensional model (without interaction with the environment) and an electric field of 1,000 V cm^{-1}.

4.2.3 Coagulation in Acoustic Field - J. W. Hann and W. Köppen commented in 1889 on an observation by Ch. E. Guillaume of fog dispersion after cannon grenade explosions. The explanation given was the accelerated precipitation of fog droplets. A systematic investigation of this subject was performed by Andrade da Costa (1936), by Brandt and Hiedemann (1936) and by Brandt et al (1937). They investigated the coagulation of smoke particles by acoustic waves. The latter found that for cigarett smoke particles the most effective range is between 5 to 50 kHz. These ultrasonic frequencies were highly absorbed by the medium. Andrade further mentioned an important observation that two small spheres in a vibrating medium repel each other if the line of their centers is parrallel to the vibration vector, and attract each other if normal to it.

These observations later were exploited for fog dispersion by Tverskoi (1960) and for many applications in science and industry (see Mednikov's book, 1965). Except for several experiments made with powerful sirens at airports (e.g., in Israel) most of the studies were confined to laboratories. Larca and Capuz (1969) observed the artificial precipitation of fogs at frequencies between 5,000 and 15,000 Hz and Viltsev (1969) reported on much faster fog dispersion in an acoustic field generated in a chamber of 500 m^3 volume. However, Podzimek (1971) was unable to detect any influence by sonic and ultrasonic waves on the phase transition in a supercooled artificial fog. Recently, a systematic study of acoustic coagulation in aerosols has been started under Prof. Shaw at the New York State University, Buffalo, New York.

One can simplify the equation for particle motion in an acoustic field in such a way that the gravitational term, the term associated with acceleration of the medium by displacement of the particle and the so-called Bassett's term can be neglected (e.g., Fuchs, 1959). From the equation of particle motion under an acoustic field characterized by its velocity $v = A \sin(\omega t)$ and a particle velocity $v_r = A_r \sin(\omega t - \phi)$ one obtains a general solution (Katchurin, 1973):

$$v_r = (v_r)_o e^{-\frac{t}{\lambda}} + \frac{A}{\sqrt{1+\lambda^2\omega^2}} \sin(\omega t - \text{arc tg } \lambda\omega) , \qquad (17)$$

where $\lambda = \frac{2}{9} \frac{\rho r^2}{\eta}$ (ρ = particle density; r = particle radius; η = dynamic viscosity). Most important is the ratio of particle to air amplitude $K = \frac{A_r}{A} = [1 + \lambda^2\omega^2]^{-1/2}$ and its derivation $-|\frac{dK}{dr}|_{max}$. The maximum value of $\frac{dK}{dr}$ indicates the most effective coagulation and smoke or fog dispersion. For the case of acoustic coagulation of water droplets in air, one finds the following frequencies (corresponding to different dK/kr_{max}): 200 Hz for r = 10 μm; 3,800 Hz for r = 2 μm and 90,000 Hz for r = 1.0 μm.

However, the strong absorption of sound waves strongly limits the application of sound waves for fog dispersion on a large scale.

Recently several authors mention experiments that combine acoustic coagulation techniques with hygroscopic nuclei seeding or with thermal methods (e.g., Katchurin, 1973). No results of similar experiments have been reported yet.

4.3 Evaporation

Evaporation of fog drops or a substantial change in the droplet size distribution can be accomplished in several ways; unfortunately only a few of them have been applied in the atmosphere or in large laboratory simulation chambers. They can be divided into methods using direct heating of the air, heating combined with artificial air motion, mixing of air masses, absorption of solar radiation and heating by laser beam.

4.3.1 Heating of Foggy Air - This technique has been known for several decades and is known under the name FIDO. Some investigators prefer to use the name "passive heating" in order to indicate that in this case air is not blown simultaneously by generators into the foggy space. Because the principles of this method are of primary importance in fog dispersion it is worthwhile to mention more details. This part will be based in essence on the approach by Katchurin (1973) which represents a simplified one-dimensional model. The main deficiency of this model is the insufficient coupling of the foggy air mass with the environment and the ground; however, it shows in a very instructive way the evolution of microstructure of the heated fog parcel.

Two equations describe the fog's microstructure: one the time change of relative humidity f, the second the time change of droplet size r.

$$-\frac{df}{dt} = f \frac{L}{kT^2} \frac{dT}{dt} + \frac{4\pi D^* n' \mu P}{kNT} \left[(f-1) \int_0^\infty r \, \zeta(r) dr - \frac{2\sigma\mu}{\rho kNT} \right] \tag{18}$$

$$-\frac{dr}{dt} = \frac{1}{r^2} \frac{2\sigma\mu^2 D^* E}{(\rho kNT)} - \frac{1}{r} (f-1) \frac{D^* \mu E}{\rho kNT} , \tag{19}$$

where f is the relative humidity, t - the time, L - latent heat of condensation of water vapor, k - Boltzmann's constant, T - absolute temperature, D* - corrected diffusion term for water vapor, n' - total concentration of water drops $[g^{-1}]$, μ - molecular weight of water vapor, P - air pressure, N - Avogadro's number, r - droplet radius, ζ(r) - density function of the droplet radius distribution, σ - surface tension, and E - saturated water vapor pressure in the environment.

Two basic assumptions are made:

1. The nuclei which remain after droplet evaporation will not influence further physical processes in the foggy air.

2. The rate of temperature change $\frac{dT}{dt}$ can be related to the rate of heating in the following way:

For a unit mass of foggy air the heat change is

$$\frac{dQ}{dt} = (c_{pa} + cq_T') \frac{dT}{dt} - L\frac{dq_T'}{dt} , \tag{20}$$

where c_{pa} is the specific heat of humid air, c - specific heat of water, q_T' - relative specific humidity (grams of liquid water per gram of fog). In the case of military smoke the values of q_T', L and c have to be changed. The last equation can be expressed in terms of the size distribution of droplets

$$\frac{dQ}{dt} = (c_{pa} + cq_T') \frac{dT}{dt} - 4\pi L\rho n' \int_0^\infty r^2 \zeta(r) \frac{\partial r}{\partial t} dr. \tag{21}$$

Because one can assume $c_{pa} >> cq_T'$ and

$$(c_{pa} + cq_T') >> 4\pi L\rho n' \int_0^\infty r^2 \zeta(r) \frac{\partial r}{\partial t} dr$$

the assumption of $\frac{dQ}{dt} \sim \frac{dT}{dt}$ is admissible.

Burning an amount of fuel dm having a specific-heat-release coefficient α and a water-vapor-release coefficient α' one obtains two equations ($c_p \approx c_{pfog}$)

$$\alpha dm = c_p \frac{N}{\mu} dT - L \frac{N}{\mu} dq_T' \tag{22}$$

$$\alpha' dm - dq_T' = ds \equiv \frac{\mu}{MP} dE \equiv \frac{\mu}{MP} \frac{LE}{kT^2} dT. \qquad (23)$$

M is the molecular weight of air and P is the saturated air pressure. By eliminating dT in the equation one finds an expression for the change of liquid water with the amount of fuel burned:

$$-\frac{dq_T'}{dm} = \frac{\alpha \frac{\mu^2}{MP} \frac{LE}{kT^2} - c_p N \alpha'}{c_p N + LN \frac{\mu}{MP} \frac{LE}{kT^2}}. \qquad (24)$$

The change in liquid water content can be easily related to the visibility which in turn can be approximately expressed by eq. (3) which yields for a total droplet concentration $n = 100\ cm^{-3}$

$$\ell \doteq 33\ q_T^{-2/3} \qquad (25)$$

and

$$dq_T = -\frac{3}{2} \frac{q_T}{\ell} d\ell\ , \qquad (26)$$

where ℓ is the visibility range and q_T is the mass of water. Finally one might ask how the visibility improves as a function of the amount of fuel burned for instance if $\alpha = 10^4\ cal\ g^{-1}$ and $\alpha' = 1.4\ g(H_2O)\ g^{-1}(fuel)$, then

$$\frac{d\ell}{\ell} = \frac{2}{3} \frac{\alpha \frac{\mu^2}{MP} \frac{LE}{kT^2} - c_p N \alpha'}{c_p N + LN \frac{\mu}{MP} \frac{LE}{kT^2}} \frac{dm}{q_T}\ , \qquad (27)$$

where ℓ, T, q_T, and m are functions of time. However, q_T is related to ℓ by eq. (25). Also, q_T and m are related to f by eq. (23). Disregarding for the moment the very important assumption of adiabaticity leading to eq. (27) (which would mean the underestimation of heat needed for fog dispersion), one can calculate from eq. (19) $\overline{r} = \overline{r}(t)$; from eq. (24) $q_T' = q_T'(t)$, resp. $n' = n'(t)$ and from eq. (27) $\ell = \ell(t)$ if the time change of m (or Q, or T) is known. However, some simple assumptions are needed for the heat transport above the (heated) ground.

The simplest assumption is a linear time dependence for the consumption of fuel which leads on the average to e.g., $dT_o/dt = 10^{-3}$°C sec^{-1}. For the case of initial and environmental conditions ($q_o = 0.15\ gm^{-3}$; $n_o' = 4.0 \times 10^5\ g^{-1}$; $T_o = 273$°K) and homogeneous temperature stratification calculations were made. The results are shown in Figures 3 and 4 where the parameters n', $\bar{r}$, ℓ and q_T are plotted as a function of time. It is apparent that during the first 400 sec there is no substantial change in mean fog droplet radius and in visibility. Then suddenly the mean droplet size starts to decrease and the visibility improves. The evolution of a real droplet size spectrum is shown in Fig. 5. This scheme can be applied for a rough estimate of the amount of fuel needed to disperse a fog through heating and droplet evaporation. Usually one assumes that an increase in air temperature of 1°C is sufficient for fog dispersion. This roughly corresponds to 0.75 tons per hr. if one considers a foggy space above a surface 50 m x 1,000 m (Katchurin, 1973) and under conditions similar to those depicted in Figures 3 and 4.

Passive heating of the air has been practically applied in the FIDO system which occasionally has operated at several airports. Stewart (1960) reports on field trials which used 3 parallel lines of FIDO burners 900 yards long and were performed in 1959-1960 at Marham (England). The conclusion was that a shallow dense fog can be cleared. However, probably for economical reasons there was some hesitations in continuing the operation. Details of the FIDO operation at London and necessary requirements for successful fog dispersion were outlined by McDonald (1960).

Even disregarding the economic aspects, which certainly would not play a decisive role in a military operation, one has the impression that the simple mechanism of droplet evaporation would not be applicable for clearing of a military smoke composed e.g., of phosphorus particles. One feels that it might be applicable for a natural fog or fog of highly hygroscopic particles which are in equilibrium with the environment.

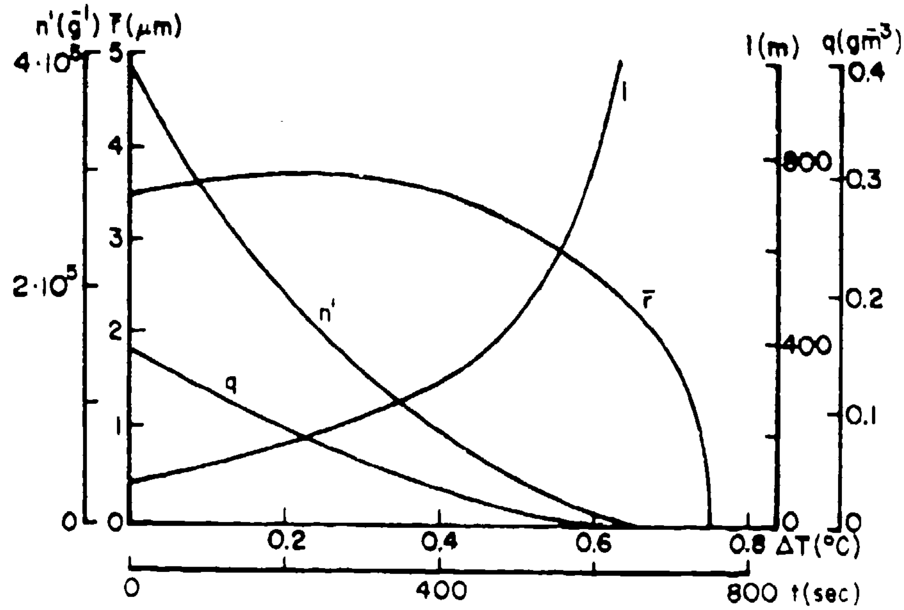

Fig. 3. The change of the mean drop radius $\bar{r}$ [μm], specific droplet concentration n' [g^{-1}], liquid water content [gm^{-3}] and visual range ℓ [m] with the time. The fog with the initial liquid water content q_0 = 0.15 gm^{-3} was heated steadily at the ground. All other parameters are identical with those under 4.3.1. Katchurin (1973, p. 238).

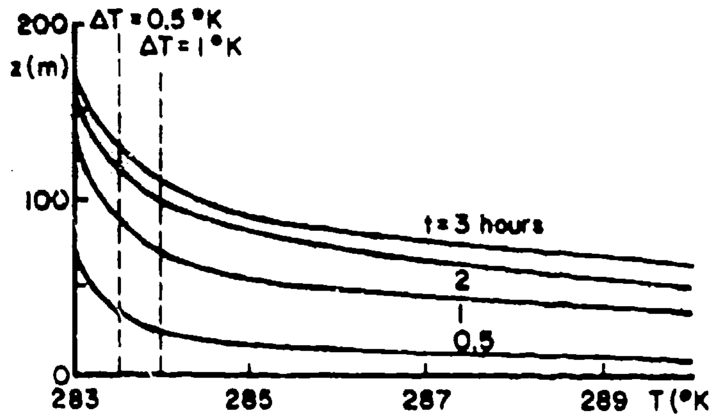

Fig. 4. The relationship between temperature, altitude and time for turbulent heat exchange above the heated ground, environmental temperature T_∞ = 283°K; heated ground temperature T_O = 323°K; q = 0.1 gm^{-3} and D = 0.1 m^2s^{-1}. All other parameters are identical with those under 4.3.1. Katchurin (1973, p. 224).

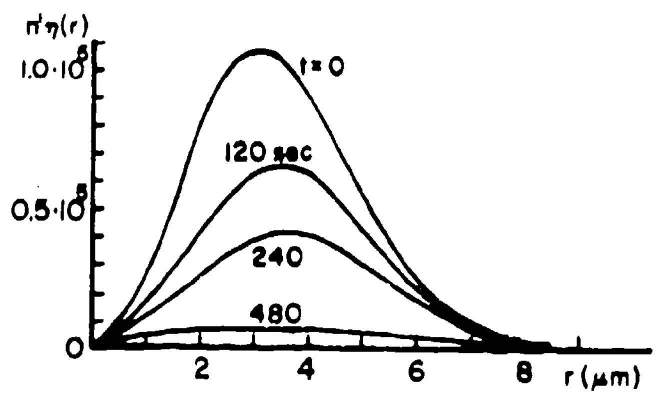

Fig. 5. Time change of the fog droplet size distribution if one assumes the following initial parameters: q_O = 0.15 gm^{-3}, T_O = 273°K, n_O^1 = 4.10^5 g^{-1}, $\dot{T}$ = 10^{-3}[$°Cs^{-1}$]. All other parameters are the same as under 4.3.1. Katchurin (1973, p. 237).

However, in a practical applica..on, the heated air always will start convection and the mixing of air masses results in dilution of the aerosol cloud. This will be discussed in the following paragraphs.

4.3.2 Combined Heating with Dynamical Method - It is very difficult to imagine passive heating of a large air mass without setting the whole environment in motion. One feels intuitively that the blowing of heated air over a large distance can be made to cover efficiently a large area if oriented in a proper wind direction. This is the basis of systems currently operating or in preparation at several airports in France and in the U.S.A. In France they are named the TURBOCLAIR system and were designed and installed by Societe Bertin et Cie at Orly and Charles de Gaule airports. The principles of this system have been described by Bertin (1964) and its operation analyzed by Serpolay (1960), Cot and Serpolay (1966) and Fabre (1971) mainly from the point of view of the results obtained during systematic field experiments on the airport Orly.

The physical description of propagation of exhaust from a jet engine has much in common with rising hot plumes in the atmosphere. One can treat both cases simultaneously, distinguishing only between the buoyancy force and the force generated by the jet engine.

Two basic equations govern the behavior of the hot air jet: first, Newton's equation for the air mass in the jet, characterized by its density ρ', mean velocity w' and the cross section of the jet S', and second, the relationship for the conservation of heat in the plume (e.g., Katchurin, 1973):

$$(\rho'S'w')g\,\frac{T'-T}{T} = (\rho'S'w')\,\frac{dw'}{dt} + w'\,\frac{d}{dt}\,(\rho'S'w') \qquad (28)$$

$$-\frac{dT'}{dz} = \frac{g}{c_p}\,\frac{T'}{T} + (T'-T)\,\frac{d}{dz}\,(\rho'S'w')\,\frac{1}{\rho'S'w'}\ . \qquad (29)$$

One assumes that the buoyancy force prevails in both cases and that c_p outside and inside of the jet (plume) has the same value. The second equation was obtained by including the change of the heat content of the parcel of air inside the plume $c_p' \rho' S' w' dT'$ with the exchange of heat from outside $c_p (T-T') d(\rho'S'w')$ and the work from Archimedes and gravitational forces during the ascent of the air mass $-(\rho'S'w')g \frac{T'-T}{T} + (\rho'S'w')g\, dz$. Primed symbols are not related to the outside air. The first term of the second equation is the change of the air temperature in the rising plume due to the adiabatic temperature change. The second term describes the heat exchange with the environment which depends on the temperature difference $(T'-T)$ and on the entrainment term $\frac{d}{dt}(\rho'S'w')$. The heat exchange in eq. (29) can be replaced by humidity exchange with the environment. For a change in specific humidity in the unsaturated air inside the plume one can write

$$\frac{dq'}{dz} = -(q'-q) \frac{d}{dz} (\rho'S'w') \frac{1}{\rho'S'w'} . \tag{30}$$

This equation may also be written in terms of relative humidity f' by replacing q' with $\frac{\mu}{M} \frac{f'E'}{p'}$ or, more accurately, with $\frac{\mu}{M} \frac{f'E'}{p'} [1 - \frac{f'E'}{p'} (1 - \frac{\mu}{M})]$, where E' is the saturated water vapor pressure in the plume at a temperature T'.

If condensation occurs an additional term related to the released latent heat must be added:

$$\frac{L}{c_p'} [(Q'-q) \frac{d}{dz} (\rho'S'w') \frac{1}{\rho'S'w'} + \frac{dQ'}{dT'} \frac{dT'}{dz}] , \tag{31}$$

where Q' is the specific humidity of saturated air inside the plume.

Many articles have been published on the subject of entrainment of environmental air into a heated air plume. Some of the results of theoretical and experimental studies are published in monographs on cloud dynamics (e.g., Schmeter, 1972). The approach often used is based on the qualitative comparison of the mass change inside of a plume $\rho'S'w'$ to the flux of the air from outside. This can be expressed for a unit of length by the comparison $\frac{d}{dz}(\rho'S'w') = \ell' v_1$, where ℓ' is the mean circumference of the plume cross section, v_1 is the mean velocity into the plume and depends mainly upon the air turbulence along the boundary. Then

$$\frac{1}{\rho' S' w'} \frac{d}{dz} (\rho' S' w') = \frac{\rho}{\rho'} \frac{v_1}{w'} \frac{\ell'}{S'} \tag{32}$$

which for a circular cross section ($\frac{\ell'}{S'} = \frac{2}{R}$, where R is the radius of the cross section) can be expressed in the form

$$\frac{1}{\rho' S' w'} \frac{d}{dz} (\rho' S' w') = \frac{C}{R} \frac{T'}{T} . \tag{33}$$

(C is a constant which has a value between 0.18 to 0.24 in accordance with measurements made in the atmosphere). C = 0.22 (Katchurin, 1973) is recommended for artificially heated air. This last equation also can be used to calculate the shape of the heated plume. After differentiation eq. (33) yields

$$\frac{2}{R} \frac{dR}{dz} = \frac{C}{R} \frac{T'}{T} - \frac{1}{w} \frac{dw}{dz} + \frac{1}{T'} \frac{dT'}{dz} + \frac{Mg}{kNT} . \tag{34}$$

Simplification of the entrainment term enables one to express the basic equations, for the force acting on a rising air parcel ($\frac{dw}{dt} = w\frac{dw}{dz}$) and for the exchange of heat and specific humidity, in a simple form:

$$\frac{1}{w} \frac{dw}{dz} = \frac{g}{w^2} \frac{T'-T}{T} - \frac{C}{R} \frac{T'}{T} \tag{35}$$

$$-\frac{1}{T'} \frac{dT'}{dz} = \frac{C}{R} \frac{T'-T}{T} + \frac{g}{c_p T} \tag{36}$$

$$-\frac{1}{q'-q} \frac{dq'}{dz} = \frac{C}{R} \frac{T'}{T} . \tag{37}$$

This system of four equations enables calculation of the four unknowns w', T', q' and R as functions of the coordinate z in the rising plume. For droplet growth or evaporation the last equation can be replaced by a similar relationship for relative humidity f' inside of the plume

$$\frac{df'}{dz} = -f'[(1 - \frac{fE}{f'E'}) \frac{C}{R} \frac{T'}{T} + \frac{L\mu}{kNT'^2} \frac{dT'}{dz} + \frac{Mg}{kNT}] . \tag{38}$$

The above mentioned can be simplified in the assumption $\frac{dR}{dz} = tg\alpha \equiv const.$ This is often used in technical applications for the region not very far or close to the source of heat. In addition, one can incorporate in the equations a horizontal wind component v by replacing the expression $\frac{C}{R}$ by $\frac{C}{R\sqrt{1+(v/w')^2}}$.

The approach mentioned above represents a strong simplification of the very complex nature of heating of air which on one hand accelerates the air mass and on the other hand dilutes the aerosol cloud. However, in the author's opinion it indicates the direction for future research on systems similar to TURBOCLAIR presently limited to measurements of the temperature distribution in the field and to attempts to deduce some semi-empirical formulas for practical applications. Along similar lines has been the attempt to disperse fog by the use of jet aircraft engines (Smith and Wexler, 1959, Serpolay, 1960, Zarea, 1962; Appleman and Coons, 1970). A more sophisticated system is currently under construction in the U.S.A. following a thorough investigation of the heating of a runway by jet type generators (Weinstein, 1973; Kunkel and Silverman, 1974; Kunkel, 1975 and 1977). In this experiment two model spaces (one 60 x 150 x 800 m, the other 30 x 150 x 400 m) will be heated by a system of 34 combustors located along two 600 m lines spaced 155 m apart. Fuel consumption of 250 gallons per minute is anticipated. For comparison, the technical parameters of the French TURBOCLAIR engines are: the emission of 50 kg sec^{-1} of air at a temperature of 500°C. The mean speed of escaping hot air is about 500 m sec^{-1} (Dubois, 1975).

While the simplified theoretical approach could be refined by theoretical studies of convection in a turbulent atmosphere, in its present form it still enables one to solve a problem important to military smoke clearing: heating of the aerosol air parcel, simultaneous dilution of particles in the unit of volume and transport of particulates to higher levels. To the author's knowledge, there is not a model currently existing which describes all three processes simultaneously. A numerical solution might yield some results important for the modeling of some of the most important interactions. The equation for the force equilibrium (eq. 35) shows that for a given amount of released heat (T_0') and a given entrainment (which will probably include C as a function of z) one can find an altitude at which $\frac{dw}{dz}$ will be zero. In other words, one should attempt to find the optimum rate of heating compared to the entrainment in order to transport the particulates at a lower concentration to a desired height. This special non-steady state case requires the sudden release of a large amount of heat. In addition, numerical modeling of convection indicates that two- or three-dimensional models can be established for quasi-steady situations (plumes, jets, and ordered convection) and known environmental parameters.

An attempt at a theoretical solution for the movement of air in the horizontal and vertical direction as an explanation for the dispersion of a fog has been made by several authors (e.g., Zilitinkevich, 1967). The technology required to introduce heat into a foggy space is the subject of many patents (e.g., from the German Patentamt one can quote No. 1208754 and 1292153 of the Société Bertin & Cie, No. 1016049 by Baier, No. 1154136 by Partl and No. 2602878 by Romatowsky).

4.3.3 Dynamical Mixing With Dry Air - Each of the methods examined sets the environmental air in motion and facilitates the circulation and transport action of the clean and dryer air into the foggy space. Many attempts have been made to introduce directly the dryer air into a fog by means of powerful ventilators. Usually the ventilators were installed along the edge of a runway and sucked the air from it. This air movement causes a downdraft of air which is supposed to be dryer and which during the descent is pseudo-adiabatically heated. A one-dimensional model for the time change of specific humidity, including the effect of turbulent diffusion, can be written in the following form

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial z} (K_z \frac{\partial q}{\partial z}) - w \frac{c_p}{L} \frac{\partial T}{\partial z} . \qquad (39)$$

The three terms on the right side of the equation are the contribution by turbulent exchange, downdraft and heating of the air (pseudo-adiabatic or adiabatic). Zilitinkevich (1967) came to the conclusion that fog dispersion by a dynamic process is possibly accomplished by droplet evaporation. His theoretical model is based on an equation similar to eq. (39).

Katchurin (1973) performed a calculation on the practical application of this method for thin layer fog dispersion. He found a reasonable improvement in the visibility over a space covered by 25 powerful ventilators (jet-engines with an air flow of 100 m^3 sec^{-1} and gas consumption of 2,000 kg hr^{-1}).

Another possible technique, considered in the U.S.A., is to use the downdraft under a helicopter. As early as 1937, it was observed that under specific conditions a thin layer of fog can be dispersed by an aircraft wake (Katheder, 1937). In 1961 it was suggested that a helicopter be used to disperse a radiation fog. In the following years a series of experiments was undertaken mainly by the U. S. Air Force. Hick (1965), Buxton et al (1968), U. S. Air Force Laboratories at Cambridge (1968 and 1969) and Katchurin (1973, pp. 220-226) described the potential and difficulties of this type of fog dispersion. This technique apparently works for a fog layer thickness less than 200 ft. if the air above the foggy space has a relative humidity below 90%. In other words, its successful operation requires the presence of a very strong temperature inversion. Remarks based on a numerical study of selected meteorological situations on the use of helicopters to clear fog, were made by Johnson et al (1974).

The application of the dynamical method for clearing of military smokes has the limitations mentioned in the literature and in addition, the disadvantages of the application of the methods based on evaporation of droplets in general. One should try, in the author's opinion, a simple experiment to see if the downdraft under a helicopter causes intense impaction of smoke particulates on the ground (covered often by vegetation) and permanent removal of a portion of them.

<u>4.3.4 Absorption of Solar Radiation</u> - Many years ago it was

suggested a warm fog could be cleared by intensive droplet evaporation by increasing the absorptive power of the foggy air irradiated by the sun. Often mentioned is carbon black as a substance, which can be easily dispersed, has high absorptive power, is relatively harmless, and is cheap.

A very simple model of the effect of increase of absorption power in a foggy layer has been considered by Katchurin (1973, p. 252-254). He assumed that the air above the fog would be seeded by carbon black powder (n g/cm^3 and of mean particle radius r). He calculated the change in temperature of the stagnant air in the environment according to the formula

$$\frac{dT}{dt} = \frac{In}{\frac{4}{3}\,\rho_p c_a \rho_a}\,\frac{\alpha}{r}\,, \qquad (40)$$

where I is the intensity of incident radiation, ρ_p is the particle density, c_a is the specific heat of the air, ρ_a is the air density and α is the coefficient of absorption of the incident radiation (dependent on the nature and size of the particle). This simplistic model (interaction with water droplets is neglected) assumes further that the heat supplied to the parcel is used fully for droplet evaporation

$$\alpha InN\pi r^2 = -L\rho_a \frac{dq}{dt}\,, \qquad (41)$$

(N is the number of absorbing substance particles per 1 g of substance) and that the change in visibility can be expressed in accordance with eq. (3) in the Introduction:

$$\frac{d\ell}{\ell dt} = \frac{In}{2q\ r\rho_p\ L\rho_a}\,. \qquad (42)$$

Katchurin (1973) used for his model the following values: $r = 0.04$ µm, $n = 10^{-5}$ gm^{-3}, $\alpha = 0.50$, $I = 1$ cal cm^{-2} min^{-1}. The other quantities correspond to the normal properties of carbon black and the air in the fog. He obtained increased visibility of 4% min^{-1} which is comparable with previously mentioned and more expensive techniques. In the author's opinion, however, this case seems unrealistic due to the assumption that the conditions in the top layer of the fog are characteristic for the whole space, that there is no interaction (optical) between the droplets of equal size and no air motion induced by the heating. The interaction with the soil, so important to fog formation, is completely neglected as in the previous modeling for other techniques.

Some of the problems of the absorption technique for fog dispersion were discussed by Fenn and Oser (1962). Qualitative observations after the seeding of layer type clouds with carbon black show that only insignificant changes of the top most layer were observed if any (Katchurin, 1973). This technique is not widely used today.

4.3.5 Evaporation of Drops in a Laser Beam - The use of a laser beam to evaporate fog droplets to improve the visibility has been considered by several authors during the last decade. Ferrara et al (1968) investigated laser beam scattering on fog droplets and outlined a solution of equations for a polydispersed fog. Kolosov (1969), using different wavelengths of laser signals (0.63, 1.15 and 3.39 μm), found that the coefficient of attenuation in an artificial fog increased linearly with the increasing liquid water content of the fog.

A systematic study on the use of laser beam for fog dispersion has been reported by several authors in the U.S.A., U.S.S.R., England and other countries. Bukatiy et al (1974) used an SO_2 laser ($\lambda = 0.63$ μm) to attempt to disperse an artificial fog. They analyzed the space and time distribution of scattered light to include the influence of convective currents. Belyaiev et al (1975) reported on experiments using a CO_2 laser ($\lambda = 10.6$ μm and 1 to $10^2 W\ cm^{-2}$) for clearing a fog along a 4 m path. A second laser (with $\lambda = 0.63$ μm) was used for attenuation measurements. The authors justified the selection of the wavelength of 10.6 μm with the high absorption of the transmitted energy by fog droplets and low absorption by air. They found a slight but permanent improvement in visibility preceded by a very short period (10 seconds) of a very significant increase in visibility.

Direct evaporation of fog droplets in a real fog or a smoke cloud seems to face many problems. In particular, the use of a wide beam will generate intense turbulent exchange along a beam. In addition, wind will drift new fog masses into the small cleared space. Some of these problems have been considered in the study by Belyaiev et al (1975).

4.4 Dilution of Aerosol Cloud

4.4.1 Horizontal Air Mixing - Horizontal mixing of air masses accompanies many of the processes leading to droplet evaporation by dynamic methods. Often it occurs as the natural phenomenon of a horizontal wind blowing into the space covered by smoke. The process can be described by an equation similar to eq. (39) in section 4.3.3 (the coordinate system must be changed and the last term on the right hand side omitted). However, the solution is very complicated if one includes the settling of particulates transported by the air motion and the wind velocity profile above the ground. One for this reason cannot apply formulas published in all standard textbooks on atmospheric diffusion deduced for turbulent diffusion. The models are usually based on a Gaussian distribution curve of pollutant concentration (Sutton, 1953).

4.4.2 Convective Dilution of an Aerosol Cloud - Much attention has been paid during the past two decades to the application of artificial convection to dilute pollutants which are concentrated on the bottom of an industrial basin in a temperature inversion. Systems of very powerful ventilators, chimneys with overheated relatively clean air and installations similar to the French Meteotron have been considered. For military application a strong updraft generated by a sudden burning of fuel has been considered.

In the case of a temperature inversion (typical for a persistent military smoke over a large area) one can assume an initial smoke density $n_o [g^{-1}]$ equation in the form of an exponential law $n_o = n_{oo} \exp(-\frac{z}{b})$, where n_{oo} is the smoke particle density at the ground at a time $t = 0$. A one-dimensional model will be described by a set of three equations, two of them identical with eqs. (35) and (36) and the third having a form

$$-\frac{1}{n'-n_0}\frac{dn'}{dz} = \frac{C}{R}\frac{T'}{T} . \qquad (43)$$

The dilution rate can be calculated from R = R(z) with a correction for particle settling. Also one could attempt a more complicated model for a sudden heating of the polluted layer at a certain point on the ground and the subsequent dilution of the air mass by a rising and diluting aerosol sphere. The starting point for such calculations could be the model used first by Sutton (1953).

4.5 Other Techniques

Many other techniques, other than those mentioned above have been described in the literature or suggested in patent applications. Most of them, such as using water screens, are unsuitable for large scale operations (e.g., Austrian Patent No. 37273, Sepulchre and No. 133646, Jahl). Other techniques are in the author's opinion not proven. Among those one finds e.g., a suggestion for increasing the precipitation of smoke particles by mixing in a fine powder of silicia monoxide which is thought will become negatively charged (Austrian Patent No. 29038, Potter, New York). Two Austrian patents (Nos. 195901 and 197807 by Waagner and Biro, and by Potocnik and Pointer) deal with enhanced coagulation in high magnetic field "filters" of smoke particles with particulates which have high magnetic moments.

Kumai and Russell (1969) studied attenuation and backscattering of infrared radiation in ice and water fog at temperatures down to -40°C. The data were used to calculate attenuation and backscattering for λ = 2.2, 2.7, 4.5, 5.75, 9.7 and 10.9 μm based on Mie theory. Several authors also suggested using infrared radiation for fog droplet evaporation at airports (e.g., German Patent No. 2005431, Industrie-Comp., Kleinewertens).

Many patents contain ideas for using hygroscopic particles of different composition or surface active substances to enhance the droplet growth by condensation or coagulation (e.g., Austrian Patent No. 183749). Others exploit a special arrangement of electric fields (e.g., German Patent No. 1159984) or acoustic waves (e.g., Austrian Patents No. 154887 by Brandt et al, and No. 162480 by Jahn and Himmelbauer) for particle precipitation. Various installations for dehumidification or warming up of foggy air also are suggested (e.g., German Patent No. 1016049, Baier); however, the author found very few of the patents included detailed analysis or results of pilot experiments.

5. FIELD EXPERIMENTS

The features of some of the experiments on warm fogs will be discussed from the point of view of the potential use of similar techniques for the clearing of military smokes.

The seeding of warm fogs with hygroscopic nuclei to increase the condensational growth of droplets and the subsequent vigorous coagulation and fallout of droplets has been performed in different ways:

Hougton and Radford (1938) suggested using a solution of concentrated calcium chloride in water at a rate of 4 to 5 liters of saturated solution per second. A similar substance was used at Cardington in England with inconclusive results. Ground and aerial seedings have been done by the staff of the Cornell Aeronautical Laboratory, Buffalo (Kocmond and Pilié, 1969) at the Elmira airport. A total of 25 ground seedings and 6 aerial seedings with NaCl were performed. Up to 700 lbs of NaCl powder was dispersed over the foggy layer. The mean diameter of the salt particles was between 10 and 30 μm. Airborne seeding was revealed to be more effective. The same group performed another series of field experiments with warm-fog seeding two years later (Kocmond et al, 1971). Several kinds of particulates were used [NaCl, Na_2HPO_4, $CO(NH_2)_2$ and polyelectrolytes] and dispersed from the aircraft. All particles improved visibility except polyelectrolytes even in a dense valley fog. The improvement in visibility diminished during a strong wind and intense turbulence and in a fog with a high liquid water content. Silverman and Smith (1970) came to a similar conclusion after warm-fog seeding with the NaCl particles. Routine warm-fog seeding with NaCl, polyelectrolytes and surfactants was done in 1969 at the Sacramento and Los Angeles airports and at Nantucket (Osmum, 1969). The results slightly contradicted Kocmond et al (1971) due to the higher efficiency of polyelectrolytes and surfactants in comparison with NaCl particles. The amount of salt solution dispersed from an aircraft flying at a normal cruising velocity was usually higher than that recommended by Hougton and Radford (1938). Over the Naval Air Station, Lemoore (Cal.) White et al (1969) used 200 gal of solution per minute during their experiments with warm-fog seeding. Large scale experiments with dispersion of giant monodisperse hygroscopic nuclei in Italy have been described by Montefinale et al (1970).

Several experiments made with urea (Silverman et al, 1972) ammonium nitrate-urea (St. Amand et al, 1971) and urea-bentonite (Depietri and Rosini, 1968) showed the potential for use of this substance for dispersion of fogs and clouds. However, some investigators stress the necessity of mixing bentonite particles of 3 μm in diameter into the urea in order to prevent fast coagulation. Several descriptions of the use of surfactants for the partial deactivation of hygroscopic nuclei or droplets during the field experiments are incomplete (Mihara, 1966; Bigg et al, 1969). In addition, the technology of nuclei passivation and the amount of deposited surfactant is largely unknown.

For the evaluation of similar techniques for the clearing of military smokes the most important information needed is which parameter was measured before the seeding experiment, and what control of the final effect was achieved. The most important microstructural parameters to be measured before the fog is seeded are: size spectrum of the droplets (or at least median drop diameter) and their number concentration, liquid water content and the same parameters for the seeding substance particles (instead of liquid water content the amount of seeding substance dispersed in a unit of time or over a certain area). Occasionally the measurement of the background nuclei concentration is quite useful. During the experiment it is useful to make several measurements of the same parameters and, in addition, the fallout rate of particulates e.g., onto a sensitized gelatine sheet.

The meteorological macroparameters which one should measure are temperature and its lapse rate, wind speed and direction, relative humidity, pressure, horizontal and vertical visibility, and total solar radiation (if needed). Very worthwhile measurements are the air turbulence (at least two components), wind profile or wind shear, some information about the fog (smoke) depth and the height from which the seeding agent is dispersed. The main meteorological parameters should be recorded during the entire experiment.

One should do preliminary modeling of the real situation and estimate the interaction between macro- and microparameters for different size distributions and the total concentration of seeding substance. One should realize that colloidal instability is a time dependent factor and that coalescence of particulates becomes significant with increasing fog (smoke) depth. The evaluation of a field test should include a detailed description of the terrain and its topography.

Any use of the thermal dispersion technique should be preceded by a detailed analysis of the possible thermal effects around the generator. Based on preliminary calculations a network of stations measuring air motion, temperature, humidity and the corresponding gradients should be established. The very extensive field test in France at Orly (Cot and Serpolay, 1966) or the preparation of the warm-fog thermokinetic dispersal system of the Air Force in the U.S.A. (Kunkel, 1977) are models of such an experiment.

Special measurements, requiring the use of aircraft, are seeding the smoke or fog layer and measuring wind speed and direction, temperature, humidity and their vertical gradients from above the layer. For successful dispersion of a warm-fog humidity less than 90% above the fog is necessary and the dispersing helicopter usually flies 100 ft above the top of the fog (U.S.A.F. Rept., 1968 and 1969; Plank, 1969).

Experiments based on the artificial convection generated by burning fuel would profit by the knowledge of the temperature field around and above the source, of its time change, and of the main meteorological parameters in the environment. Remote sensing detection of the shape of the heated air plume would be a possible solution to the problem.

6. RECOMMENDATIONS FOR FUTURE RESEARCH

This Survey of Techniques for Clearing Military Smoke Clouds is based on warm-fog clearing techniques and is written by a cloud physicist. This necessarily causes some inconsistancy between the treatment of different methods and is reflected in the structure of this report. The broadness of the field and the limited time available dictated that the author could not read in detail all cited articles. Several articles are known only from abstracts and some only are mentioned by title without key words. However, these citations are considered important and the author hopes that in the future he will have an opportunity to comment on them and to suppliment this report. In the author's opinion key words cannot replace even an abstract of an article, but do facilitate orientation in the treated subject for the reader.

The recommendations for future research are based on this survey and, in addition, notes are made on the military application of some of the existing theoretical conclusions for the systematic study of techniques for clearing military smoke clouds. In the author's opinion, the following techniques deserve more attention:

The use of highly hygroscopic substances for military smokes excludes to a large extent the fog dispersion technique of seeding with hygroscopic materials. There is a real danger that one could enhance the stability and increase the fog density instead of dispersing it. One possibility that should be checked is the effect (if any) of covering a portion of the droplet population of phosphorus particulates by an evaporation retarding layer of surfactants. For this one would need to develop a special technique to disperse the surfactant and deposit it on the surface of smoke particles. Afterward, the colloidal instability of the smoke could be enhanced by a supply of water vapor.

The coagulation technique merits attention for the reason that it can be combined with dynamical and other techniques and applied over the territory controlled by our or enemy forces. It is well known that the scavenging by spherical particles (water drops) is not very effective (Feit et al, 1970, p. 36); however, little attention has been paid to the collection efficiency of light, nonspherical particles similar to ice crystals. Their long residence time and their swinging movement certainly contribute to the effective collection of micron sized particles. This is supported by many observations in nature.

FIDO or TURBOCLAIR or any similar system hardly will be applied in the manner used at airports. One simple, and for military operations attractive, system is to use suddenly incinerated fuels spread on the ground that could generate an updraft and transports smoke particles upward and dilutes the aerosol cloud. In the author's opinion, this simple technique should be analyzed in detail because the supply of heat is accompanied with a supply of water vapor. For instance 1 gram of jet fuel produces 10^4 calories of heat and 1.4 g of water vapor (Feit et al, 1970, p. 4). It would be worthwhile to analyze the potential of this technique by a three-dimensional model for a calm situation and for horizontal wind. In general, turbulence in the atmosphere lowers the efficiency of systems similar to TURBOCLAIR, and in the case of suddenly released large amounts of heat, the efficiency of heat transformation into kinetic energy. Also the author feels that the interaction of the parcel of the foggy or smoky air with the ground has been grossly underestimated if not neglected in the majority of the models.

The simplest technique for warm-fog dispersion--the use of helicopters--has a limited application in clearing of military smokes. However, if properly applied it can enhance the effectiveness of the coagulation (scavenging) technique. For this reason studies of the flow field and supply of heat by helicopter engines similar to the investigation by Plank and Spatola (1969) are vey useful. Also there is some evidence that a helicopter downdraft could contribute to the smoke particle retention on grass and leaves of shrubs and trees.

Some of the techniques mentioned above potentially can be used to enhance several of the mechanisms previously mentioned (e.g., electrostatic charging or phoretic forces), but the author feels at this time that they will not play a decisive role.

After finishing this survey, the author found several important articles which could not be included in the literary survey. He hopes these can be added in the future because his wish is that this study should be useful and up-to-date for those who work in this field.

7. SUMMARY

This report documents the critical review conducted on the subject of clearing military screening smokes. Table I summarizes the methods available and presents an attempt to rate the suitability of the various techniques for military application. However, the author does not feel qualified to be the final judge of the relative military worth of these methods. It is recommended that CSL have this table reviewed by military users for a more informed assessment of potential military applicability.

TABLE I

EVALUATION OF THE VARIOUS SMOKE ELIMINATION TECHNIQUES

Approach to the Removal of Smoke Particles by:	Report Page	Technique	Field Experiment Results	Suitability for Clearing of Smoke	Remarks
Air Filtration	23	Deposition of fog or smoke particles on "eliminators" (mesh, deflectors, cooled grids)	Pilot experiments on runways	Fair	Most of the reported results inconclusive "Hardly applicable" (Hougton)-"Applicable for small space" (Junge)
Sedimentation	24	Simply sedimentation or sedimentation enhanced by downdraft (water drops, helicopter)	Pilot experiments in small scale with stimulated downdraft by water drops (Japan)	Fair or Poor	The author of this report suggests using grinded dry ice for induced downdraft
Phoretic Forces	25 to 27	Thermophoretical Diffussiophoretical Photophoretical Electrophoretical Forces	Limited experiments in the atmosphere (very small space) mainly with electrophoretical forces	Poor Poor Poor Fair	Combination with other techniques promising
Condensation of Vapors on Nuclei	27 to 35	Hygroscopic substances	Large scale experiments with some positive results in the case of clearing fog	Fair	Very limited applicability for hygroscopic smokes. For other smokes a combination with phoretical forces or filtration possible (addition of water vapor)
Coagulation and Sedimentation in Gravitational Field	35 to 37	Scavenging on spherical and nonspherical bodies	Small scale experiments--results conclusive only from laboratory experiments	Fair or Good	The author suggests using nonspherical porous particles and combination with elstat. forces
Coagulation and Sedimentation in Electric Field	35 to 37	Bipolarly and unipolarly charged particulates (or bubbles)	Large scale experiments with some positive results in small scale fog dispersion (inconclusive)	Fair or Good	Difficulties with the application during military operations (Vonnegut)
Coagulation and Sedimentation in Acoustic Field	39 to 40	Sonic frequencies	Large scale experiments with positive results only in small space	Fair or Poor	Limited applicability (short range, amount of energy)
		Ultrasonic frequencies	Only laboratory experiments	Bad	
Drop Evaporation through Heating of Fog	40 to 46	Hygroscopic smokes	Some positive results with warm fog seeding	Poor or Bad	Nuclei must be removed from the space (difficult)
		Oil smokes	Not known	Good or Fair	Combination with dynamical method

TABLE I

EVALUATION OF THE VARIOUS SMOKE ELIMINATION TECHNIQUES (CON'T)

Approach to the Removal of Smoke Particles by:	Report Page	Technique	Field Experiment Results	Suitability for Clearing of Smoke	Remarks
Drop Evaporation through Mixing with Dry Air	51 to 52	Blowers or ventilators	Inconclusive results from clearing fog on a small area	Bad	Energy problem, short range
		Helicopters	Some positive results	Fair	Enhancement of the downdraft
Drop Evaporation through Combined Thermal and Dynamical Method	46 to 50	Continuous heat sources	Some positive results in clearing the shallow fog layer on runways	Fair	Enormous energy necessary, hardly applicable for clearing smoke in large scale operations
		Instantaneous heat sources	Large scale experiments were not yet controlled and documented satisfactory	Good or Fair	Might be effective at low temperature inversion, however technology of successive bursts must [illegible]
Drop Evaporation by Increased Absorption of Solar Radiation	52 to 53	Carbon black seeding of fog	Showed little changes in fog or cloud structure	Bad or Poor	The amount of energy obtained by absorption of solar radiation is insufficient
Drop Evaporation by Using a Laser Beam	53 to 54	Use of laser to evaporate fog droplets	Known only in a very limited space	Bad or Poor	For smoke or fog drop evaporation unsuitable yet (space, energy)
Drop Evaporation through Infrared Radiation	53 to 54	Use of infrared heaters	Known only in a limited space	Bad to Fair	Unsuitable for larger space
Dilution of Aerosol Cloud by Horizontal Mixing	54 to 55	Simulating the horizontal wind effect by ventilators	Results of small scale experiments inconclusive	Bad	Unsuitable for large space operation
Dilution of Aerosol Cloud by Vertical Mixing	55	Dilution of aerosol by vertical air motion (ventilators, helicopters)	Not systematic experiments with smokes are known	Fair	Potential use in the case of shallow smoke layer under inversion

Excellent = method demonstrated to work with reasonable logistical requirement

Good = method expected to work with estimated logistical requirements

Fair = method expected to work, no estimate available of reasonable logistical requirements

Poor = uncertain whether method would work

Bad = method not expected to work

APPENDIX

References, Articles, Reports

Subjects of Literary Study

1. Smoke and Fog, their Microstructure and Composition. Particle Properties and Measurement:

    1.1 Concentration
    1.2 Size distribution
    1.3 Chemical composition
    1.4 Surface properties
    1.5 Optical properties
    1.6 Electric charge
    1.7 Behavior in humidity field
    1.8 Sampling by sedimentation
    1.9 Sampling by impaction
    1.10 Optical counters
    1.11 Special identification techniques

2. Meteorological and Environmental Parameters Influencing the Physico-chemical State of Military Smoke and Fog:

    2.1 Temperature
    2.2 Humidity
    2.3 Wind vector
    2.4 Solar radiation and other parameters
    2.5 Atmospheric stability
    2.6 Turbulence-scale and intensity
    2.7 State of the soil

3. Methods of Smoke and Fog Generation in the Field:

    3.1 Continuous generators (point source)

3.2 Line generator

3.3 Surface source

3.4 Chemical reaction in the air

3.5 Explosions - instantaneous point source

4. Improvement of the Visibility in Military Smoke or Fog by:

4.1 Changing the concentration and size distribution of particulates by sedimentation, coagulation, particle deposition under force field, etc.

4.2 Addition (decrease) of humidity

4.3 Addition of active and inactive particulates

4.4 Electrical charging of particulates

4.5 Coagulation in acoustic field

4.6 Changing of optical parameters of particulate cloud

4.7 Intensifying the cloud by dilution (air mixing)

4.8 Changing of the homogeneity of an aerosol cloud

5. Modes of Applying Heat Generators, Seeding Agents and other Fog Dispersing Facilities in the Field:

5.1 FIDO type systems

5.2 Exothermic reactions

5.3 Absorption of radiation

5.4 Quasi-adiabatic warming of the air

5.5 Air mixing

5.6 Increase of droplet mass by condensation

5.7 Generators of acoustic waves

5.8 Electrostatic generators

5.9 Scavenging techniques

5.10 Filtration techniques

5.11 Generators of heat combined with intense turbulence

5.12 Other experiments

6. Survey of Field Experiments (Description, Results):

6.1 Natural fog dispersion

6.2 Artificial fog dispersion

6.3 Smog dispersion

6.4 Smoke clearing

Abbas, M. A. and J. Latham 1967

The Instability of Evaporating Charged Drops, J. Fluid Mech., 30, 663-670.

4.2 - 4.4 - 5.6

Adam, J. R. and R. G. Semonin 1970

Collection Efficiences of Raindrops for Submicron Particulates, in Precipitation Scavenging (1970), U.S. AEC, Oak Ridge, Tenn. December, 151-160.

The scavenging efficiency of falling raindrops through a biological aerosol is investigated. 1 μm Bacillus Subtilis spores were used and scavenging efficiency of 0.004% for a 2 mm water drop were found.

5.9

Adamy, L., and E. Meszaros 1967

Possibilities of Artificial Dispersion of Fog in Hungary Budapes, Idojaras, 71, 28-33, 9 ref.

2.1 to 2.7 - 4.1 to 4.8

Alliez, J. and C. Lafargue 1977

Electrisation de gouttes de solutions salines aqueuses par evaporation ou par condensation de la vapeur d'eau, J. Rech. Atmos., 11, 121-139.

The authors measured the charge effect on the drops of salt aqueous solution (LiCl) at different humidities and rates of condensation or evaporation. In conclusion it was found that the condensation gives rise to positive charges and the evaporation to negative charges. Besides these charges, charges carried by the drops obtained by pulverization of an aqueous saline solution which are in equilibrium with the environment were measured.

1.6 - 4.4

Amelin. A. G. 1948

Bildung von übersättigtem Dampf und Aerosol durch Mischen von Gasen, die Dämpfe enthalten und verschiedene Temperatur haben, Kolliod. Zhur. USSR, 10, 169.

4.2 - 5.6

American Meteorological Society 1968

AMS Statement on Weather Modification, Weatherwise, Boston, 21: 100-101.

General survey including the standpoint to the "cold" and "warm" fog seeding is presented.

6.1

Anderson, E. 1924

Some factors and principles involved in the separation and collection of Dust, Mist and Fume from Gases: Trans. Amer. Inst. Chem. Engin. 16, Part I, 69-86.

General treatment of subject; particle size ranges of several common products are given. Discussed are separation by 1) gravitation, 2) inertia, 3) filtration, 4) spraying, and 5) electrical means.

1.1 - 1.2 - 1.6 - 4.1 - 4.4

Andrade, E. N. da Costa 1936

The coagulation of smoke by supersonic vibrations. Trans. Faraday Soc., 32, 1111-1115.

Spheres at rest in a vibrating medium repel each other if the line of their centers is parallel to the vibration vector, and attract each other if normal to it. Force varies inversely as the fourth power of the distance, and directly as the maximum velocity of a vibrating fluid. The author derives a formula for the time t during which the number N of the particles is halved.

4.5

Andro, M., and R. Serpolay 1970

Comparison des rendements en germes de glace obtenus par pulverisation de propane et d' anhydride carbonique dans un brouillard surfondu, J. Rech. Atmos. 4, 93-100.

The authors checked the efficiency of the liquid propane and of the dry ice. They counted the number of ice crystals generated in supercooled fog at the temperature of -15°C. The efficiencies of both substances varied not considerably between -5°C and -15°C and were approximately the same.

4.3 - 5.6

Annis, B. K., A. P. Malinauskas and E. A. Mason 1973

Theory of Diffusiophoresis of Spherical Aerosol Particles and of Drag in a Gas Mixture, Aerosol Sci., 4, 271-281.

The equations describing the motion of a spherical aerosol particle in a diffusing gas mixture are presented. They cover the free molecule regime to continuum regime. The results include the previously published formulas as a special case.

4.1 - 5.9

Appleman, H. S. 1968

The AWS Weather Modification Program, Proc. 1st Nat. Conf. Weather Modif., AMS, Boston, 3860 395.

6.1

Appleman, H. S. 1968

The operational Dissipation of Supercooled Fog, Proc. Int. Conf. on Cloud Physics, Univ. of Toronto, Aug., 708-712.

El-mendorf AFB near Anchorage has 67 hrs. per year fogs more dense than 0.5 mile of visibility. Seeding with dry ice by special airplanes at the rate 12.5 and 25 pounds per mile is recommended. Also, liquid CO_2 was successfully used. From 37 operations in supercooled fogs 25 were successful.

6.1

Appleman, H. S. 1968

First Report on the Air Weather Service Weather-Modification Program, April 1968, U. S. Air Weather Service, Techn. Rep. 203, May, 14 p.

Several methods were selected for bringing them to a state of operational readiness: Dispersion of supercooled fogs over runways was the most feasible.

6.1

Appleman, H. S. 1969

Second Annual Survey Report on the Air Weather Service Weather-Modification Program (FY 1969), U. S. Air Weather Service, Tech. Rep. 213, June.

Report is intended to inform the AWS community of the current status. Supercooled fog dissipation; CO_2, AgI techniques considered fully operational; propane technique is far too cumbersome for routine use. Na NO_3 in warm-fog dissipation offers a possible but impractical and costly solution.

6.1

Appleman, H. S. 1969

Introduction to Weather Modification, U. S. Air Weather Service, Techn. Rep. 177, 36 pp.

A summary and description of all the used techniques in different programs in the U.S.A. and abroad is presented.

6.1

Appleman, H. T., and F. G. Coons, Jr. 1970

Use of Jet Aircraft Engines to Dissipate Warm Fog, J. Appl. Met. Boston, 9: 464-467.

Positive results were observed: In 5 min. raised the visibility from 1000 ft. over 1/2 mile.

5.1 - 5.11 - 6.1

Arakawa, H. 1960

Fog - Shelter Net at Kegon Fall Area, Milan, Geofis. Pura e Applic., 47, 195-198.

6.1

ARMY CHEM. CENTER 1958

Spray Dissemination of Agents, Symp. VIII. Vol 1, C.W.L. Special Publ. No. 2, Army Chem. Center, Md., July 158 pp.

10 papers dealing with various properties of aerosols and sprays from the aspect of dissemination incl. the aircraft spraying.

3.1 to 3.4

ARMY CHEM. CENTER 1953

Symposium V. Aerosols. Conducted by Chem. and Radiol. Lab. Army Chem. Center, Md., June, 145 pp.

Content: 12 papers discussing generation and properties of cond. nuclei, military smokes. Included are optical properties of aerosols.

1.1 to 1.6

Axford, D. W. E., K. F. Sawyer, and T. M. Sugden 1948

The Physical Investigation of Certain Hygroscopic Aerosols, Proc. Royal Soc. (London), Ser. A., Vol. 195, 13-33

Two different kinds of smoke are compared: 1) a smoke of known physical and chemical properties formed from hygroscopic substances by spray atomizing in a chamber 2) complex smoke produced by the propellant when a gun is fired. This theory of light scattering by transparent spheres in the range of 0.1 to 2.0 µm particle diameter has been found valid for hygroscopic screening smokes.

1.3 - 1.5 - 4.6

Aufm Kampe, H. J., J. J. Kelly and H. K. Weickmann 1957

Seeding Experiments in Subcooled Stratus Clouds, Meteor. Monographs, 2: 86-111.

The experiments with supercooled fog dispersion on an area of 300 km^2 are described. With the aid of 25 aircrafts the fog or stratus cloud on an area of 30,000 km^2 can be dispersed.

5.12

Bakanov, S. P. and B. V. Deryaguin 1961

K voprosu sostoiania gaza, dvizhuschevosia vblizi tverdoi poverkhnosti, Dokl. AN SSSR, 139, 71-74.

The general problem of the behavior of the gas in the proximity of a solid surface is discussed from the standpoint of mechanics of non-equilibrium state gases. Comparison with the Maxwell solution is made.

4.1

Bakanov, S. P., and B. V. Deryaguin 1959

O teorii termoprecipitatsii vysokodispersnykh aerozolnykh system, Koll. Zhur. 21, 377-384.

An equation for the mean velocity of particulates embedded in a field of a temperature gradient is deduced. The deduction is based on the gas kinetical approach with the application of Sonine polynomials.

4.1 - 5.9

Bakhanova, R. A., E. G. Solianek, and F. S. Terziev 1968

Rezul'taty opytov po bor'be s tumanami isparenia v Kol'skom zalive zimoi 1966-1967 g.; Meteorologia i gidrologiia, Moscow, No. 10:39-43.

Films of surface active agents (fatty alcohols as 3% solution in kerosine) were used. Dispersing the fog on 3 km^2 surface was observed (water should be free of ice and it is necessary to know the currents in the bay).

4.3 - 6.1

Bakhanova, R. A., et al. 1970

Rezultaty ispitanii metodov vozdeistvia na tuman parenia, Trudy UNIGMI, 77, 144-151.

Results of laboratory study of the effect of surface-active film on a water surface to prevent evaporation and thus to eliminate the fogs are summarized. Positive results of the experiment at Kola Bay (3% solution of higher fatty alcohols dissolved in kerosene, and spread over an area of 3 km^2 (visibility 10-12 km) are justified). (The results of the investigation of methods of acting on evaporation fog.)

4.3 - 6.1

Baldit, A. 1931

Le probleme de la dissipation du brouillard, Meteorologie, Paris, 7: 383-397.

2.1 - 2.7

Balabanova, V. N. 1960

Crystallization of Super-Cooled Fog by Silver Iodide, Moscow, Izv. AN, Ser. Geofiz., 1658-1662.

It was found that the output of ice crystals increases with increase of amount of introduced crystallization nuclei only up to a definite value. Further increase leads to no further ice crystal output. The conclusion is reached that ice crystals in fog are mainly found by the freezing of liquid water drops on striking particles of the silver iodide.

5.12

Barth, W. 1959

Grundlegende Untersuchungen über die Reinigunsleistung von Wassertröpfchen, Staub, 19, 175-180.

Water spray is used for the removal of dust from the exhaust gases. This is a basic investigation in cleaning capacity of water drops.

4.1

Battan, L. J. 1968

Some Problems in Changing the Weather, Weatherwise, Boston, 21: 102-105.

General conclusions related to weather modification including fog dispersion are made. Limited possibilities in dispersing warm fogs and clouds are stressed.

6.1

Beckwith, W. B. 1975

Airport Fog Dispersal System, Airport Forum, Wiesbaden, 5, 13-19

The article outlines and analyzes different systems of fog dispersion techniques at the airports. The main reason is to make a comparison of the costs of a fog dispersion at the airport and of the equipment necessary for safe landing.

6.1

Belyaieva, I. I., and N. S. Smirnov 1959

Precipitation of artificial fogs, Koll. Zhur. SSSR, 21, 4, 385-387.

Ionizing irradiation of humid air increases the number and dimensions of particles producing fog. Quality of precipitated fog depends on duration and intensity of irradiation.

1.6 - 4.4

Belyaiev, V. I., V. V. Vialcev, and I. S. Pavlova 1966

An Experiment in Influencing the Weather by the Seeding of Fog with Dry Ice., Izv. ANSSSR, Fis. Atmos. i Ckeana, 2, 630-635 5 ref.

5.12

Belyaiev, V. I., I. S. Pavlova and V. M. Ryabov 1969

Sur la methode de dispersion des nauges sur les grandes superficies, Izv. AN SSSR, Ser. Geofiz, 9, 1410-1416.

The authors discuss the cloud seeding from a plane flying above the foggy layer. The amount of the dispersed dry ice is 100 g/km for a fog of the thickness of 100 m and 250 g/km for a thickness of 400 m.

5.12

Belyaiev, V. P. et al 1975

Eksperimentalnye issledovania prosvetlenia tumana lazernym izluchenien s - 10.6 μm, Izv. AN SSSR, Fizika Atmos. i Okeana, 11, 1075-1078.

(Experimental investigation on the transmittance of a laser radiation with - 10.6 μm through a fog.)

A CO_2 laser was used in a cloud chamber with a laser beam path of 4m (horizontal) in order to observe a clearing effect of the laser beam. For initial optical thickness of fog $\sigma = 0.63$ was calculated the final effect assuming different velocities of crosswind and a single value of the diameter of the laser. A simple model is presented which shows a good agreement with experiment.

1.5

Benson, C. S. 1970

Ice Fog., Weather, London 25: 10-18.

Detailed synoptic, physico-chemical and microstructural characteristics of the fogs in Alaska (Fairbanks).

1.1 - 1.2 - 1.5 - 2.5

Berg, T. G. O. 1967

Nucleation and Growth in Cloud Seeding, Sky Water Conf. 1st, Denver July 1967, Proceedings of Sky Water Conf. 1 (on) Physics and Chemistry of Nucleation, Denver, U. S. Bureau of Reclamation, 1967 (1969, 127-146).

Description of the experiments with positively charged drops suspended in a nonuniform AC field at a high humidity and a low temperature, during which AgI particles of predominantly negative charges are introduced into the vessel. The ice-particles formed chains under influence of electric fields.

1.6 - 4.4

Berlyand, M. E. and O. I. Kurenbin 1969

Atmospheric pollutant diffusion in calm winds, Tr. GGO, No. 238.

2.5 - 3.1 - 3.2

Berlyand, M. E. and R. I. Onikul 1968 a

On the theory of air mass transformation and fog formation, (in Russian), Tr. GGO, No. 207.

2.5 - 2.6

Berlyand, M. E., R. I. Onikul and G. V. Ryabova 1968 b

The theory of atmospheric diffusion under foggy conditions, Tr. GGO, No. 207.

2.5 - 3.1 - 3.2

Berlyand, M. E. (Editor) 1973

Air Pollution and Atmospheric Diffusion, Transl. from Russian by A. Baruch. J. Wiley, New York

The monograph deals with all possible aspects of air pollutants and their behavior in the atmosphere.

2.1 to 2.7 - 3.1 to 3.4

Berlyand, M. E. 1975

Sovremennye problemy atmosfernoi diffuzii i zagraznenia atmosfery, Gidrometeoizdat, Leningrad, 448 pp.

A monograph dedicated to "Current problems of atmospheric diffusion and air pollution" contains the elements of diffusion and propagation of pollutants in the atmosphere, the transformation of pollutants, air pollution monitoring and practical calculation of pollutant dispersion. A useful list of publications mainly of Russian authors and a content in English are attached.

2.5 - 2.6 - 3.1 - 3.2 - 3.3 - 3.4

Bertin, J. 1964

La désénbulation par turboréacteur. Le procédé "Turboclair" 4e Congres ICAA, Turin, June, 7 pp.

The author reviewed the experiments by Serpolay with propane and by the method FIDO. Starting in 1958 one attempted to apply new procedure for the dispersion of warm fogs on the airports (Orly, Betigny, Melun and Mont-de-Marsan). The results are not yet conclusive.

5.1 - 5.12 - 6.1

Bigg, F. K., J. L. Brownscombe and W. J. Thompson 1969

Fog modification with long chain alcohols, J. Appl. Met. 8, 75-82.

For the supression of water evaporation from droplets of 1 μ radius one has to use 5 kg of the surfactant for km³ of space. This procedure should be applied just before the formation of a dense fog because due to the evaporation the temperature drops to 0.5°C below the dew point. Hexa- and octadecanol was used with an iodide esther at a temperature of nebulisation of 350°C. Four experiments at Sydney in 1967 cannot lead to any final conclusion of the efficiency of the methods.

4.3 - 6.1

Bigg, E. K., and J. L. Brownscombe 1969

Fog modification with long-chain alcohols, J. Appl. Met. 8: 75-82.

The growth of water drops on condensation nuclei in a supersaturated environment can be greatly retarded by the presence of long-chain alcohols which form monomolecular layers on the liquid surface. Field trials are described in which about 200 kg of a hexadecanol-octadecanol mixture was released. Assessment of the value of the method and of a positive result is difficult.

4.3 - 6.1

Boutaric, A. 1937

Quelques remarques sur la production et les properiétés des brouillards artificiels, Météorologie, Paris, Ser. 4, 1, 8-15.

1.1 - 1.2 - 1.3 - 1.5

Bowen, D. 1966

A New Way of Clearing Fog. New Scientist, London 32, 583.

6.1

Bowen, E. G. 1968

Review of Current Australia Cloud Seeding Activities. Nat. Conf. on Weather Modif., 1st., Albany, N. Y., April 28 - May 1, Proceedings.

Review on Australian cloud seeding activity is presented. More emphasis is put on basic research of cloud physical processes.

6.1

Bradley, W. E., and R. G. Semonin 1969

Effect of Space Charge on Atmospheric Electrification, Cloud Charging and Precipitation, J. Geophys. Res., 74, 1930.

1.6 - 4.4

Brandt, O. and E. Hiedemann 1936

Über das Verhalten von Aerosolen im akustischen Feld, Kolloid Zeitschr., 75, 129-135

Coagulation and precipitation of particles in ultrasonic waves. Found a range of 5 to 50 kHz most suitable.

4.5

Brock, J. R. 1968

The Diffusion Force in the Transition Region of Knudsen Number, J. Coll. Interface Sci. 27, 95-100.

The free molecule theory of diffusiophoresis is reviewed and extended into the region of moderately large particles for binary mixture and equimolar counterdiffusion and for diffusion through the second stagnant component. A reasonable agreement with the theory was found.

4.1 - 5.9

Brandt, O., H. Freund and E. Hiedemann 1937

Schwebstoffe im Schallfeld, Zeitschr. Physik, 104, 511-533

Derive formula for ratio of amplitudes of vibration of the particle and of the gaseous medium. Similitude considerations of critical numbers and theory of acoustic coagulation are attached.

4.5

Brunt, D. 1936

The dissipation of fog. Trans. Farad. Soc., 32, 1264-1270.

2.1 - 2.7

Buikov, M. V., and I. P. Polovina 1969

Nekoterye zakonomernosti rasprostraneniia isskustvennoi kristallizatsii v pereokhlazdennykh sloistykh oblakakh, Trudy Nauchno-Issled. Instituta, Kiev, 82, 61-71.

The analysis of data of observations of the propagation of zones of artificial crystallization when stratus clouds are seeded with solid CO_2 is presented. Three factors were beared in mind: condens. growth of crystals, turbul. diffusion of crystals, dropping of crystals under the action of gravity. Experimental values of the width of the crystallization zone at two instances were used in finding the turbulent diffusion coefficient.

5.12

Bukatyi, V. I. et al 1974

Teplovoie deistvie nepreryvnogo izluchenia SO_2 -lazera na iskustvennyi tuman, Dokl. AN. SSSR, Ser. Mat. -Fiz. 218, 558-561.

A detailed analysis is presented about the fog dispersion with the use of SO_2 laser (λ = 0.63 μm). An apparatus for measuring the partial and temporary distribution of signals is described. A good agreement between the calculated and measured data was found (including the influence of convective currents).

4.6 - 5.3

Buikov, M. B. and I. P. Polovina 1970

Ob evolutsii sloistoobraznykh oblakov i tumanov i ikh iskustvennom rasseianii, Trudy VIII Vses. konf. po fizike oblakov i aktiv. vozdeistviam, Gidrometeoizdat, Leningrad, 451-456

General description of the activity of UNIGMI, Kiev in the field of the dissipation of clouds and fogs.

6.1

Bullrich, K. and G. Hänel 1978

Effects of Organic Aerosol Constituents on Extinction and Absorption Coefficients and Liquid Water Contents of Fogs and Clouds. Pageoph, Vol. 116, pp 293-301.

Organic particulate matter will partly dissolve in water condensed on it or will form a film on the drop surface. Effects will be: reduction of surface tension of drop thus increasing the equilibrium drop size or film on surface will reduce diffusion of water molecules to drop. Tables are presented for main time and continental type aerosols for extinction and absorption coefficient effects and surface tension effects. The effects of diffusion inhibition appears to be greater than the reduction of surface tension.

4.3 - 4.6

Burke, T. P. and G. Balu 1968

Nebbia artificiale, Assoc. Geofisica Italiana, 16th Naples, May 1967, 517-518.

A laboratory method is described for producing a stable artificial fog. The conditions simulate those which cause the formation of fog. (Artificial fogs.)

2.1 - 2.2 - 2.5

Burtsev, I. I. 1973

Iskusstvennye vozdeistvia na meteorologicheskie protsessy vo Frantsii, Trudy Nauchnogo Vysokogorn. Geofiz. Instituta, Nalchik, USSR, 22, 3-11.

(Artificial modification of meteorological processes in France.)

The author summarizes the main efforts in France in the field of artificial interference with the weather. A considerable part of the report is dedicated to the description of the trials with the clearing of supercooled and warm fog. The author claims that in this field the French scientists were successful.

6.1

Burtsev, I. I. and S. G. Malakhov 1968

Vymyvanie osadkami produktov delenia iz oblachnogo sloia atmosfery, Izv. AN SSSR, Fizika Atmos. i. Okeana, 3, 328-334.

(Rain scavenging of the decay products from the layer below the clouds in the atmosphere.) The authors concluded from the measurement of the radioactivity of natural decay products on two different levels in Kaukazus mountains that the scavenging coefficient in the equation was 9.10^{-5} sec^{-1} for snow and 3.10^{-5} sec^{-1} for the water drops.

5.9

Businger, J. A., and P. S. Arya 1974

Height of the mixed layer in the stably stratified planetary boundary layer, in Turbulent Diffusion in Environmental Pollution, Adv. in Geophys., Academic Press, New York, 73-92.

Modeling a steady state stable boundary layer causes difficulties because of the transition from turbulent to laminar regime with increasing height. An attempt is made to describe the complex transient interactions between these two regimes. With increasing stability the length scales of vertical motion become independent of the height above the surface.

2.5 - 2.6

Buxton, E. B., R. A. Chechile, and J. G. Davis 1968

Feasibility Study for a Rotor Lifted Water Droplet System to Disperse Warm Fog, NWRF 43-0368-135, Farmington, Conn., Un-Aircraft Corp. Syst. Center, Contract N00189-67-C-1130, Fiscal Rep., 4°, pp. 93, 21 ref.

4.1 - 5.9

Calder, K. L. 1948

The Diffusive Properties of the Lower Atmosphere, Monograph, No. 9.401, Perman, Record of Res. and Develop. Porton.

The survey about the diffusive properties of the lower atmosphere based on the experiments performed at the Chemical Defense Experimental Station, Porton. The thermal and dynamical structure of the lower air layers is considered. The application of different diffusional models is anticipated and the comparison with the experimental measurements is done.

3.1 - 3.2

Cadle, R. D. 1965

Particle Size; Theory and industrial applications, Reinhold Publ. Corp., New York, 390 pp.

The monograph covers all main fields of physical and chemical properties of aerosols. Special attention is paid to the instrumentation and evaluation of particle measurements.

1.1 to 1.11

Carpenter, L. J. 1947

Fog Investigation, Panama Canal, I.C.S. Memo 151, Dept. of Operation and Maintenance, Spec. Engin. Division, Diablo Heights, C.Z., 8 pp.

1.6 - 4.4 - 5.6

Carstens, J. C., J. Podzimek and A. Saad 1974

On the Analysis of the Condensational Growth of a Stationary Cloud in the Vicinity of Activation, J. Atmos. Sci., 31, 592-596.

The authors analyse the growth of a stationary drop into a size where both condensation and thermal accommodation coefficients play a role. The growth equation is integrated under constant ambient conditions and approximate solution of the growth rate of a drop approaching to the equilibrium is suggested.

4.3 - 5.6

Charry, H. A. and R. L. Lininger 1975

AWS Handbook of Ground-Based Cold Fog Dissipation Using Vented Liquid Propane. Vol. I. Theory and practice, U. S. Air Weather Service. Tech. Rep. (AWS-TR-75-255), July, 54 p.

A detailed analysis of the physical processes accompanying the clearing of supercooled fogs by the use of liquid propane is presented. The different factors influencing the clearing of fog are outlined.

5.12 - 6.1

Carrol, J. W., and P. N. Keller 1976

Electrostatic Induction Parameters to Attain Maximum Spray Charge to Clear Fog., Naval Weapons Center, China Lake, Jan.

A detailed analysis of charging of sprayed water drops by corona and by induction. The theory of induction charging sprays from cone nozzles is in agreement with the experimental results. It is possible to charge spray drops up to one-quarter of the Rayleigh limit. The individual factors, influencing the charging of drops by induction method are analyzed and their importance for highly charged droplet outlined.

1.6 - 4.4 - 6.1

CHEMICAL CORPS 1953

A Basic Study of the Physics of Aerosol Formation. Bibliographic Appendix. Final Tech. Rep. U. S. Army Chem. Corps Labs, Contr. No. DA-18-064-CML-1402, July 1, 210 p.

Enlarged edition of De Juhasz 1948: Spray chem. atomization, solid particles and fundamentals.

1.1 to 1.11

Chiang, Ta-Kuan, and M. C. Gourdine 1973

Field Evaluation of an Electrogasdynamic Fog Dispersal Concept, Part 1, Washington FAA, Syst. Res. Dev. Serv., Rep. No. FAA-RD-73-33, pp. 79.

4.3 - 6.1

Chikirova, G. A. 1967

Issledovanie kinetiki pogloschenila vlagi chastitsami ionoobmennykh smol v srede, nasyschennoi vodiannym parom, i v tumane, Trudy GGO, Leningrad, 202, 60-64.

Laboratory tests were made with ion exchange resin absorbing water vapor in saturated medium or in fog. On the basis of the experiments it cannot be recommended to use these particles for cloud seeding as hygroscopic nuclei. (The investigation of the water absorption of the ionexchanging resins in the environment saturated by water vapor and in a fog.)

4.3

Chiang, T., M. C. Gourdine, T. Wright, and R. Clark 1973

Field Evaluation of an Electrogasdynamic Fog Dispersal Concept, Gourdine Systems, Inc., Livingston, N. J., 134 pp.

1.6 - 4.4 - 5.6

Clark, R. S. 1969

Project Foggy Cloud, Eleventh Interagency Conf. Weather Modif., NAVWEARSCHFAC Tech. Paper No. 26-69, 27-29.

6.1

Clark, T. L., and W. D. Hall 1978

A numerical experiment on stochastic condensation theory, submitted to J. Atmos. Sci., 31 pp.

A stochastic model has been established in which a three-dimentional "deformation" term and the fluctuating velocities $[\overline{(u')^2}]^{1/2} = [\overline{(v')^2}]^{1/2} = 46.6$ cm sec^{-1} and $[\overline{(w')^2}]^{1/2} = 69.1$ cm sec^{-1} were used. The model showed that the irreversible coupling caused by the finite values of relaxation time can produce significant small-scale variability in the horizontal.

1.7 - 2.2 - 2.6 - 4.2

Coons, F. G. 1968

Project Warm Fog - Final Report, Washington, Air Weath. Serv. Tech. Rep. 209, 1, pp. 5-20.

6.1

Occhet, R. 1952

L' évolution d'une gouttelette d' eau chargée dans un nuage a température positive, Annales de Geophys. 8, 33-54.

1.6 - 4.4

Coons, F. G. 1972

Some Preliminary Results from the FAA Fog Dispersal Program Boston, AMS, Int. Conf. Aerospace Aeronaut. Met., May 1972, Washington, 225-227.

4.3 - 5.1 - 6.1

Corrin, M. L., J. R. Connell and A. J. Gero 1974

An Assessment of Warm Fog-Nucleation, Control and Recommended Research, NASA Contr. Rep. CR-2477, Washington, D. C., Nov.

Very detailed survey of the state of warm fog research. Effects of surfactants, surface films and coagulation. Collision efficiencies of drops are compared as calculated by different authors: Hocking-Jonas, Shafrir-Neighburger, Klett-Davis. A survey of field experiments is attached with a critical evaluation of the results of warm fog dispersion. Special paragraphs are dedicated to the role of turbulence and airflow in the fog dispersion and to the instrumentation used.

4.1 to 4.5 - 5.1 to 5.5 - 6.1

Corrsin, S. 1974

Limitation of gradient transport models in random walks and in turbulence, in Turbulent Diffusion in Environmental Pollution, Adv. in Geophys., Academic Press, New York, 25-60.

The author presents an interesting analysis of the gradient transport in models for turbulence.

2.6 - 3.1

Cot, P. D. 1964

Resultats opérationels d' une methode de dissipation des brouillards surfondus, C. R. Acad. Sci. 258, 3337-3338.

The author describes the techniques used for the dispersion of supercooled fogs, such as: dry ice, the drops of liquid propane. The experiments were performed on the airport Paris-Orly with a positive result.

5.12 - 6.1

Cot, P. D. and R. Serpolay 1961

Nouveaux résultats d' ensemencement des brouillards surfondus a l' aide de pulvérisation de propane liquide, C.R. Acad. Sci. 253, 171-173.

At the airport Paris-Orly were performed several experiments with seeding of fogs (below 0°C) with the liquid propane. Positive results were observed.

5.12

Cot, P. D. and R. Serpolay 1966

Les recherches de dissipation thermique des brouillards réalisées a l' aéroport d' Orly, J. Rech. Atmos. 2, 171-177.

The rough calculations of the necessary overheating of the foggy air in order to reach the corresponding evaporation of drops is between ΔT = 1.6 to 2.5°C. A crane moving on a rail supported a T-piece of 80 m wide on which a set of 6 vertical strings was suspended with the cables for thermometers. In this way the effect of exhaust gases emitted from the jet engine could be checked. In 1965 experiments were made which show that on the test field 150 x 200 m at the air temperature +6°C the fog was cleared 100 m from the jet engine, where the air started to ascend.

5.1 - 5.2

Dana, M. T. 1970

Scavenging of Soluble Dye Particles by Rain, in Precipitation Scavenging (1970), U.S. AEC, Oak Ridge, Tenn., December, 137-147.

Field experiments with uranin and rhodamine dye particles atomized from an air-jet sprayer were performed at Olympic Peninsula median particle radius ranges from 0.4 to 7.5 µm. For particles larger than 3.0 µm a good agreement with the simple inertial capture model was obtained. Smaller particles captured were much more numerous than predicted by theory.

5.9

Csürös, Z. 1959

Die Rolle oberflächenaktiven Substanzen bei der Benetzung von verschiedenen Industrie-Stauben, Period. Polytechn. Chem. Engin. Hungary, 3, 2, 67-86.

Two methods of testing are described: blasting the deposited dust, and using the dust chamber for testing dust suspension.

4.3

Davies, C. N. 1966

Aerosol Science, Academic Press, London, New York, 468 pp.

A monograph on all basic problems related to aerosol includes contributions by several authors such as generation, coagulation and electrical charging of aerosols. Phoretical forces, theory and experimental investigation of filtration mechanism are treated in details. Special chapters are dedicated to optical properties and deposition of aerosols.

1.2 - 1.3 - 1.5 - 1.6 - 1.10

Davies, C. N. 1973

Air Filtration, Acad. Press, London, New York, 171 pp.

A survey about the theory of air filtration and its confrontation with measurements. Includes many useful references on the application of the theory of filtration and a list of publications.

1.9 - 4.1 - 5.9

Davis, L. G., and R. Papania 1969

Warm Fog Dispersal Operations. Los Angeles International Airport and Sacramento Metropolitan Airport California, January-April 1969, Boulder, Col. BG Aug. G In., Envir. Serv. Op., Final Rep. 4°, pp. 32, 4 ref.

6.1

Davis, M. H. 1964

Two Charged Spherical Conductors in a Uniform Electric Field. Q. J. Mech. and Appl. Math. 17, 499.

1.6 - 4.4

Davis M. H. 1965

The Effect of Electric Charges and Fields on Collision of Very Small Cloud Drops, Proc. Internat. Conf. Cloud Phys., Tokyo and Sapporo, 118-120

1.6 - 4.4 - 5.6

Davis, M. H. and J. D. Sartor 1967

Theoretical Collision Efficiencies for Small Cloud Droplets in Stokes Flow, Nature, 215: 1371-1372.

The Hocking's theory predicted on the basis of Stokes flow around two colliding drops that no collision occurs between drops of similar size. (The radii of which are smaller than 19 μ.) Both authors extending Hocking's theory found possible explanation of collision efficiency below the radius of 20 μ.

4.1

Deacon, E. L. 1946

Screening Smoke - Their Properties, Production and Use, Part II.

The Meteorology and Assessment of Smoke Screens, Ministry of Supply, Monograph No. 9.208, Porton, Nov.

1.1 - 1.2 - 2.1 to 2.6

Day, G. J. 1972

Atmospheric Dispersion over Long Ranges-Longitudinal Expansion of the Cloud from a Moving Point Line Source, Tech. Note No. 115 CDETN 115, Porton Feb.

3.2

Deacon, E. L. 1949

Vertical diffusion in the lowest layers of the atmosphere, Quart. J. Roy. Met. Soc. 75, 89-103.

2.5 - 2.6 - 3.2

de Almeida, F. C. 1977

Collision Efficiency, Collision Angle and Impact Velocity of Hydrodynamically Interacting Cloud Drops: A Numerical Study, J. Atmos. Sci., 34, 1286-1292.

The model is based on the assumption of two interacting spheres (drops) falling in the air. For this reason a more general term for calculating the collision term was used.

4.1 - 5.9

de Bary, E. and F. Rössler 1970

Computation of the Particle Concentration from Measurements of Scattered Radiation in the Stratospheric Dust Layer, Beitr. Zur Phys. der Atmosph. 43, 87-92.

The article deals with the calculation of the concentration of AN from the scattered radiation measured from rocket sounding and balloon ascents. AN concentrations were estimated in the dust layer of maximal density above the tropopause.

1.5

Deardorff, J. 1978

Different approaches toward predicting pollutant dispersion in the boundary layer, and thei- advantages and disadvantages, in the Proc. WMO Symposium on Boundary Layer Physics Applied to Specific Problems of Air Pollution, Norrköping, WMO, No. 510, Geneva, 1-8.

The author discusses several methods for describing the behavior of pollutants in the atmospheric boundary layer. For vertical diffusion from the surface non-Gaussian models and mixed layer scaling are recommended. The mixed layer scaling is also applicable to fumigation condition. Very difficult seems to be nighttime boundary layer.

2.5 - 2.6 - 3.1 - 3.2

De Juhasz, K. J. 1950

Spray Literature Abstracts, Publ. with support of NSF and Amer. Soc. of Mech. Engin., New York, 383 p.

Literature Abstracts contains the survey of articles and reports published on spray aerosols including general information on the physico-chemical properties of aerosol prepared in the laboratory or in nature. Each reference is accompanied by a short summary and contains information about the extent of an article and number of quotations.

1.1 to 1.11

De Juhasz, K. J. 1964

Spray Literature Abstracts, Vol. II, Publ. with support of Div. of Air Pollution, Bureau of State Services, Public Health Service, U. S. Dep. of Health, Education and Welfare, Washington, D. C., 384 pp.

Vol. II is a continuation of Vol. I of 1950. The author collected literary notes on spray aerosols until 1962 and ordered them according to the author index.

1.1 to 1.11

Depietri, C., and E. Rosini 1968

Inseminazione mediante aereo con una miscela urea-bentonite di nubi cumuliformi, Assoz. Geofisica Italiana, 16-th, Naples, May 22-24.

Aircraft seeding of cumuliform clouds with a mixture of urea-bentonite. Urea-Particles with diameters of 70μ are dispersed from an airplane. Bentonite particles of 3μ in diameter were mixed into urea particles to prevent their coagulation. Dissolutions of cumulus clouds after 15 min. were observed.

5.6 - 5.9 - 6.1

Delcambre, 1933

Sur la destruction du brouillard. Météorologie, Suppl., No. 2, 28-29.

4.1

Deryaguin, B. V. and S. S. Dukhin 1956

Ob osazhdenii chastits aerozolei na poverkhnosti fazovogo perekhoda. Znachenie v meditsine. Dokl. AN SSSR, 3, 613-616.

General and very simplified equation was deduced for the force acting on a particle. The comparison of a simple calculation of the efficiency of this process with the real situation leads to the conclusion that this process might have a significance in medicine. (On the deposition of aerosol particles on the surface of phase transition. Significance in medicine.)

1.7 - 4.1

Deryaguin, B. V., and S. P. Bakanov 1957

Teoria dvizhenia malykh aerozolnykh chastits v pole diffuzii Dokl. AN SSSR, 117, 959-962.

The authors deduced a mean velocity of the movement of an aerosol particle in the environment characterized by the diffusion of two kinds of molecules. (The theory of small particle motion in the diffusion field.)

4.1 - 5.9

Deryaguin, B. V. and Yu. I. Yalamov 1971

Theory of the thermophoresis of moderately large aerosol particles, with allowance of thermal gas slip and the temperature jump at the particle surface, Koll. Zh. 33, 294-330.

The authors calculated the rate of thermophoresis acting on a moderately large particle (Kn ^ 0.1) using a continuous model of a gas through a porous "aerosol diafragm". The force acting on a particle increases with thermal slip coefficient.

4.1 - 5.9

Deryaguin, B. V. and Yu. L. Yalamov 1964

Teoria termoforeza umereno bolschikh aerozolnykh chastits Dokl. AN SSSR, 155, 886-889.

Deduction of the velocity of a micron size particle (in which internal heat transfer cannot be neglected) is made. The correction term represents a considerable deviation from the formula deduced for very small particles (r smaller than mean free path of air molecules.)

4.1

Deryaguin, B. V., Yu. I. Yalamov and V. S. Galoyan 1971

Theory of the thermophoresis of moderately large volatile aerosol particles, Koll. Zh. 33, 509-514.

Volatile aerosol particles have a large diffusional settling rate in the concentration gradient of gas mixtures. The thermophoresis rate differs substantially from the rate of moderately large nonvolatile particles.

4.1 - 5.9

Dessens, H. 1957

La prevention et la dissipation des brouillards, C.N.R.S. Obs. Puy de Dôme, 3, 10-20.

The author analyses his methods utilized for the fog dispersion and makes a useful classification of them.

6.1

Dirnagl, K. 1955

Messtechnische Probleme bei der einheitlichen Beurteilung von Nebeln und Verneblern. Zeitschr. Aerosol-Forsch. u. Therapie, 4. 291-400.

The author describes the criteria which should be used in order to evaluate the effectiveness of the medical generators: quantity, density, degree of atomization. Atomization for inhalation uses the size range of 0.1 to 100 μm diameter. Some problems with the particle collection (with the aid of cascade impactors) are described.

1.1 - 1.2 - 1.9

Dieckmann, A. 1931

Versuch zur Niederschlagsmessung aus treibendem Nebel, Meteor. Zeitschr. 66, 400-402.

The description of the method for the measurement of the deposition of water droplets on a wire or a wire net placed on the top of a rain gauge.

4.1

Downie, C. A. and B. H. Silverman 1958

Military Applications of Supercooled Cloud and Fog Dissipation, Air Force Surveys in Geophysics, 118: 44 p. (AFCRC T 59-635).

T e authors examine briefly the physics of dissipation of supercooled fog and stratus with the use of dry-ice. Discuss seeding experiments and their techniques. During periods of bad weather, the seeding technique has potential applications for military operations.

5.12

Doyle, A., D. R. Moffett and B. Vonnegut 1964

Behavior of Evaporating Electrically Charged Droplets J. Coll. Sci., 19, 136-143.

4.2 - 4.4 - 5.6

Dubois, E. 1975

La dissipation des brouillards chaudes sur les pistes d'aérodromes, La Météorologie, Num. Spec. Aviation et Météorologie, Nov. 41-52.

The TURBOCLAIR system for the fog dissipation is described. Several degrees of the temperature increase is sufficient for the fog dispersion. The turbojet engine provides 50 kg sec^{-1} of air at a temperature of 500°C, emitted at a speed of about 500 m/sec. The history of the development of the system before its installation at the airport Charles De Gaulle in 1974 is presented.

5.2

Drozin, V. G. and V. K. LaMer 1959

The determination of the particle size distribution of aerosols by precipitation of charged particles, J. Coll. Sci. 14: 74-90.

The described method is based on measuring a macroscopic property of a large number of particles (10^{9}) charged in a corona discharge and precipitated in an electric field. The number of charges acquired by the particles is a single valued function of particle size.

From the knowledge of this function and measured values of current (or accumulated charges) vs. time, the size distribution curve can be determined. One test, including calculation, takes about 20 min. Experiments were carried out with particles in the submicron range. Method cannot be applied at present to particles smaller than 0.2 μm because their charging follows another law, for which further investigation is necessary.

1.2 - 1.6 - 4.4

Dukhin, S. S., and B. V. Deryaguin 1964

Primenenie termodinamiki neobratimykh processov k teorii kapillarnogo osmosa i diffuzioforeza, Dokl. AN SSSR, 159, 401-404.

The use of Onsager's relations shows how to express the capillary forces and diffusiophoretic forces in semipermeable medium. (The application of the thermodynamics of irreversible processes to the theory of capillary osmosis and diffusiophoresis.)

4.1 - 5.9

Dukhin, F. F. 1960

Theory of motion of an aerosol particle in a standing sound wave, Koll. Zh. USSR. 22: 128-130.

Aerosol particles assume different concentration in the nodes and in the antinodes in a standing sound wave. The particles wander to and concentrate in the plane of nodes; for particles larger than 0.1 μm the thermophoretic forces are not great enough to counter act the wandering of particles toward the nodes.

4.5

Dukhin, S. D. and B. V. Deryaguin 1958

Method of calculating the deposition of disperse particles in a stream around an obstable (in Russian) Koll. Zh. USSR, 20, 326-328.

Deposition of inertialess particulates from an aerosol flow on an obstacle in the presence of an external field of force. Also, calculate the precipitation by gravitational forces, of inertialess particles suspended in water on an ascending bubble.

1.9 - 4.1

Dull, J. M., A. J. Moore, J. L. Dunn, and E. L. Pendleton 1972

Test of Polyhydric Chemicals for Fog Dispersal, Rept. No. FAA-RD-72-13, Interim Rept., Phase I., Dow Chemical, Texas Div., Freeport, January, 55 pp.

Trials were conducted at Arcata-Eureka airport and in Redwood Valley, Cal. with rotating impactors and with a disc particulator. Particles with mean diameter of 50 μm of following chemicals were finally dispersed: Glycerin, diethylene glycol and tetraethylene glycol. Visibility improvement in fog was observed.

4.3

Eadie, W. J. 1969

Computer Simulation of Fog Seeding Experiments, U. S. NASA, Spec. Public. SP-212, 75-85.

Computer model used during the Project Fog Drop (which helped to optimize the seeding technique for a wide variety of warm fog situations) is described and some results presented.

2.1 to 2.7 - 4.3 - 5.6

Eddy, A. and W. Vickers 1962

Dispersal of Supercooled Fog and Stratus Cloud, AFCRL-62-685, Burlington, Mass., Tech. Ops. Inc., Contr. No. AF 19 (604) - 8049, Final Rep., pp. 25.

5.12

Egner, D. O. and D. Campbell 1960

Aerosol Impaction on Small Diameter Collectors. Rep. CWLR-2352, (Chem. Corp. Res. and Dev. Labs), Feb., 24p.

Describe collection efficiency of droplets of different size on ribbon-like and cylindrical sampling devices of 0.1 to 1.0 inch dia. Collection of droplets in the 5 to 100 μm range is most sensitive to the diameter of the collector. Wind speed and other factors have smaller influence on the collection of droplets.

4.1

Egner, D. O., D. Campbell and O. R. Mumford 1960

Micrometeorological Effects on the Downwind Travel of Aerosols. Army Chem. Warfare Labs., Army Chem Center, Md. CWL Spec. Publ. 1-14, Jan., 25 p.

Various combinations of wind speeds, release altitudes and temperature gradients were used to determine their effects on downwind travel of particulates. The effect of the altitude of the release of the particles for zero temperature lapse rate and various wind speeds is discussed. The effect of meteorological conditions is studied for the case of a release altitude of 1.5 m and a wind speed of 1.0 m/s.

2.3 - 2.5 - 3.1

Eichborn, J. L. von 1954

Abhängigkeit der Sinkgeschwindigkeit der oberen Grenze bei Rauch- und Nebelsäulen von Beleuchtungs-Stärke. Koll. Zeitschr. 135, 49-50.

The author found that the sinking velocity of smoke or fog is in the morning sunshine 15 to 20 times greater than the value observed in cloudy weather or in evening dusk. This finding has a bearing on agricultural spraying of insecticides and fungicides.

2.5 - 3.3

Eichborn, J. L. von 1954

Über die Sedimentation von Rauch und Nebel und die Zunahme der Sinkgeschwindigkeit ihrer oberen Grenze mit der Beleuchtungsstärke, Zeitschr. f. Aerosol-Forschung u. Therapie, 3, 279-284 and 374-391.

Three cases of sedimentation of a cloud of aerosol particles falling inside of a cylindrical tube are discussed: 1) Particle concentration is low - the settling velocity can be calculated from the Stokes law and the particles do not interfere, 2) the concentration is high and the cloud fills completely the cross section of the tube - the sinking velocity depends on the counter flow of air through the channels; 3) the concentration is high, but the cloud does not touch the walls the cloud falls like a porous body of low specific gravity much faster than would the individual particles.

1.8 - 4.1

Eichborn, J. L. von 1955

Partikelbeweglichkeit, Verhältnis vom Brownscher Bewegung zu Fallbewegung, und Gruppeneinteilung suspendierter Partikel, Zeitschr. f. Aerosol-Forschung u. Therapie, 4, 453-465.

Discussed are: the proportionality factor between velocity of fluid and resistance (Stokes and Stokes-Cunningham formula), the relationship of the Brownian displacement, the thermal energy of the molecule, Brownian movement and falling speed of particles. Conclusions are made about coagulation and precipitation of particulates.

1.8 - 1.9 - 4.1

Eichborn, J. L. von 1955

Bewegungswiederstand von Schuttgut- und Staubpartikeln als "Umstromungswiederstand" und "Durchstromungswiederstand" zwischen Partikeln; Strömungsphysikalische Gesetze, Der Maschienenmarkt, 55, 4-8.

Discussion of the flow pattern around an obstacle (a spherical particle) and through it (in a pipe). Shows the flow lines of transition from through flow to surrounding flow and the change from laminar to turbulent flow. The significance of Reynolds number is mentioned in relation to other physical parameters and Froude's number.

1.9 - 4.1

Ellison, J. Mck. 1954

Errors in Particle Size Determination from Settled Suspensions, Nature, 173: 948.

An experiment is described during which the particle size distribution was examined on the substrate and in space (using a picture of particles "frozen in" the gelatin). Patterson-Cawood groticule was used and particles were classified according to their projected area.

1.2

Eredia, F. 1939

La dissoluzione della nebbia. Ala d'Ital, 20, No. 1, 25-29.

6.1

Fabre, R. 1969

Phenomènes optiques provoqués par ensemencement d' un brouillard surfondu à température voisine de -6°C. J. Rech. Atmos. 2, 101-103.

During fog dispersal several optical phenomena were observed.

5.12 - 6.1

Fabre, R. 1968

Improvement of visibility over airport runways during foggy weather Pt. 1, Study of fog and its effect on air traffic: procedures of improving visibility, Transl. by G. S. Rinehart. White Sands Missile Range, *New Mexico*, Atm. Sciences Lab., U. S. Army Electronis Command, Feb. 51 p.

Detailed description of fog origin and means for dispersing it is presented. It is concluded that presently the problem of supercooled fog dissipation is almost resolved, although warm fog dissipation remains a more difficult task which awaits its solution in future.

6.1

Fabre, R. 1971

Aéroport d'Orly-Installation de Dénébulation Turboclair, Rept. by the Aeroport de Paris and Société Bertin et Cie, 39 pp.

6.1

Facy, L. 1960

Les Mecanismes Naturels de Lessivage de l'Atmosphère, Geofisica Pura e Applicata 45, 201-215.

The author discusses different ways of capturing small particulates by coalescence with water droplets or snow crystals, by the deposition of particulates in a gradient of vapor pressure. Also is discussed capturing by ground and by vegetation.

4.1

Faraday Society, London 1936

Disperse systems in gases; dust, smoke and fog; a general discussion. London, pub. by Gurney and Jackson

1.1 to 1.11

Fedorov, E. K. 1967

Aktivnoie vozdeistvie na meteorologicheskie protsessy, Meteorologia i Gidrologia, Sbornik statiei, Gidrometeoizdat, Leningrad, 215-226.

The historical development of cloud physics including the weather modification and the study of nuclei is presented. Many details about the goal and interrelationships of the Russian programs in this field together with the respective references are mentioned.

6.1

Fedoseev, V. A. 1971

Use of Hygroscopic Substances in Influencing Water Aerosols. I. in Advances in Aerosol Physics, V. A. Fedoseev, No. 3, Israel Progr. Sci. Transl. Jerusalem, 1-10

Historical development of interference into the rain, cloud and fog formation since 1932 - 1933 mainly in the Turkmenian Institute of Rain.

6.1

Fedoseev, V. A. (Ed.) 1971

Advances in Aerosol Physics, Israel Progr. for Sci. Transl.

1.1 to 1.11

Fenn, R., and H. Oser 1962

Theoretical Considerations on the Effectiveness of Carbon Seeding, NSASRDL Tech. Rept. 2258, Fort Monmouth, N. J. 29.

5.3

Feit, D. M., E. E. Hindman, II, D. B. Johnson, and F. K. Tag 1970

Warm Fog Dispersal Techniques, NAVWEARSCHFAC, Tech. Pap. No. 1 - 69 (REV), Navy Weather Res. Facility, Norfolk, October.

The study pays attention to the principles and meteorological conditions of a successful dispersion of a warm fog. The function of TURBOCLAIR and of similar systems are analyzed and compared with other techniques such as air mixing and seeding with hygroscopic substances.

4.3 - 5.1 - 5.2 - 5.4 - 6.1

Ferrara, R., G. Fiocco, and G. Tonna 1968

Scattering di un fascio laser in nebbia, Instituto di Fisica dell'Atmosphera, Rome, Italy Sci. Rep. IFA SR No. 23, Oct.

The angular distribution of a laser beam scattered by a cloud is analyzed and the radiation spectrum of drops is derived. The initial equation in the case of a polydisperse foggy medium is solved.

1.5

Ferrara, R. 1970

Spettri dei raggi delle gocce di nebbia determinati con un metodo ottico, Geofisica e Meteorologia, Genoa, 19: 1-2.

He-Ne laser beam scattering in an artificial fog was used and droplet radii were deduced. The angular distribution is determined by five photometers at different angles toward the direction of the incident beam. Artificial fog was produced in 40 m^3 chamber. (Size spectrum of fog droplets determined by an optical method.)

1.5

Findeisen, W. 1932

Messungen der Grösse und Anzahl der Nebeltröpfchen zum Studium der Koagulation inhomogenen Nebels, Gerl. Beitr. Geophys., 35, 295-340.

The author outlines a simple theory of the coagulation of fog droplets which is applied to the explanation of the size spectrum distribution of droplets in an artificial fog. An optical technique is used for the drop size distribution measurement based on the photographing of all drops within a space limited by the phocus depth of the system.

1.1 - 1.2 - 4.1

Finkelstein, L. 1947

Symposium on Particulates, Army Chemical Center, p. 13

1.1 - 1.11

Finkelstein, L. 1964

History of Research and Development of the Chemical Warfare Service, 4 Vols. Vol. 1, p. 7, June

1.1 to 1.5

Flynn, R. G., and W. B. Beckwith 1968

Airline Warm Fog Dispersal Test Program, Tests at Sacramento, California, 15 November, 1967-8, March 1968, Part. 1, Washington, Air Trans. Assoc. Amer. 4°, pp. 104, 12 ref.

6.1

Frankenberger, E. 1930

Über die Koagulation von Wolken und Nebel, Physik. Z. Leipzig, 31, 835-840.

4.1

Foitzik, L. 1950

Zur meteorologischen Optik von Dunst und Nebel, Zeitschr. f. Meteor. 4, 289-297 and 4, 321-329.

A detailed analysis of the light scattering on the fog droplets. The calculation was made for the Gauss-size distribution of droplets.

1.5 - 4.6

Frenkiel, F. N. and R. E. Munn 1974

Turbulent Diffusion in Environmental Pollution, Proc. Sympos. IUTAM & IUGG, Charlottesville, Virginia, April, 1973, in Advances in Geophys. Acad. Press, New York, Vol. 18A (462 pp.) and Vol. 18B (389 pp.).

Collected papers dealing with theoretical problem of atmospheric turbulence and diffusion. Vol. 18A contains mainly contribution to the study of turbulence in the atmosphere and in the laboratory, Vol. 18B is dedicated to the diffusion of pollutants.

2.5 - 2.6 - 3.1 - 3.2

Friedlander, S. K. 1960

Similarity considerations for the particle size spectrum of a coagulating, sedimenting aerosol, J. Meteorol., 17, 479-483.

The similarity observed among size distributions of natural aerosols measured at different places and times is explained on the basis of the kinetics of aerosol coagulation and settling. The dimensional analysis enables to shape the upper end of the spectrum which agrees well with available experimental data. The calculation estimates the rate at which matter is transferred from lower to the upper end of spectrum.

1.2

Fuchs, N. A. 1959

Isparenie i rost kapel v gazoobraznoi srede, Itogi i Nauki, Izd. AN SSSR, Moskva, 1958, 92 pp. Evaporation and Droplet Growth in Gaseous Media Transl. by J. M. Pratt, Pergamon Press, New YORK, 72 pp.

The book deals with: 1) evaporation or growth of a drop being motionless relative to the medium. 2) Quasistationary evaporation of droplets in a stream of gas. 3) Non stationary case of evaporation or growth.

5.6

Fuchs, N. A. 1955

Makhanika aerozolei, Izd. Akad. Nauk SSSR, Moskva, 353 pp. The Mechanics of Aerosols, Pergamon Press, London 1946, 488 pp.

Includes: 1) Classification of aerosols, dimensions and shapes of particles, 2) recti-linear motion, uniform, 3) non-uniform motion, 4) curvilinear motion, 5) Brownian movement and diffusion, 7) coagulation, 8) transformation of powdery substances into the aerosol stage.

1.1 - 1.2 - 1.4 - 1.5 - 1.6 - 1.8 - 1.9

Fuchs, N. A. and A. G. Sutugin 1970

Highly Dispersed Aerosols, Transl. by Israel Program for Sc.. Translat. Ann Arbor Science Publ., Ann Arbor

The authors discuss the physical properties of highly dispersed aerosols including the description of their generation.

1.1 - 1.2

Fukuta, N. 1968

Some Remarks on Ice Nucleation by Metaldehyde. Proc. Int. Conf. on Cloud Physics, Toronto, Aug. 194-198.

Metaldehyde, Nucleation, and Testing in Yellowstone Park is described with some positive results. Two shapes of ice crystals (2 or more hexagon plates eccentrically placed; hexagon plates with sectors attached almost perpendicularly to them were found.

5.12 - 6.1

Gaivorovskii, I. I., L. I. Krasnovskaya and U. A. Seregin 1963

Artificial Disposal of Supercooled Clouds and Fogs, Publ. IAMAP, No. 13, 144 pp.

The authors describe the use of the dry ice for the fog dispersion in the USSR. Laboratory studies with the AgI are performed.

5.12 - 6.1

Gaivoronskii, I. I. and Ju. A. Seregin 1962

The Dispersal of Supercooled Fogs from the Earth (In Russian) Moscow, Trudy Centr. Aero. Obs., Vyp. 44, 28-37, 2 ref.

The results of experiments are summarized in the form of tables including the beginning, and duration of fog, visibility, air temperature and wind velocity, liquid water content g/m^3, dosage g/min, time in minutes for visibility to improve to 1000m, etc.

5.12 - 6.1

Gaivoronskii, I. I., B. N. Leskov, and Yu. A. Seregin 1965

An Experiment in the Regular Application of Methods for the *Artificial Dispersal of Supercooled Clouds and Fogs* over Aerodromes, (*In Russian*), Trudy CAO, Moscow, 65, 3-8.

5.12

Gaivoronskii, I. I. 1967

Iskusstvennoie rasseianie oblakov i tumanov, in Meteorologia za 50 let Sovetskoi vlasti, Sbornik statei, E. K. Fedorov, Gidrometeoizdat, Leningrad, 243-249.

The detailed description of methods and results using CO_2 for fog and cloud seeding since 1947 is presented.

6.1

Gaivoronskii, I. I., L. I. Krasnovskaia and A. D. Soloviev 1968

Artificial Low Cloud and fog dissipation, Proc. Int. Conf. on Cloud Phys. Univ. of Toronto, Aug. 700-707.

A survey of principles applied to cloud and fog dispersion is made. The three basic groups are: Evaporation of fog droplets, droplet removal and droplet coagulation. Some technical data on successful seeding of cloud and fogs are communicated. The most successful was apparently seeding of supercooled clouds.

5.1 - 5.2 - 5.6 - 5.12 - 6.1

Gaivoronskii, I. I. 1969

Issledovaniia v oblasti vozdeistvii na oblaka i tumany, Moscow, Trudy CAO, No. 90: 56-72.

Results of the theoretical and experimental study on the mechanism of supercooled cloud and fog modification by means of ice-forming agents are reported.

6.1

Garbalewski, C. 1971

Sztuczne oddzialywania na mgly (artificial action on fog), Warsaw, PIHM, Gazeta Obs., 24, 5, 7-9

A general discussion of the possibility to disperse a fog. So· · detailed analysis of fog dispersion processes are attached.

4.1 - 4.3 - 4.4 - 4.5 - 5.1 - 5.5

Garrett, W. D. 1968

Künstliche Veränderungen der Grenzfläche Ocean/Atmosphäre, Die Umschau, Frankfurt 68: 568-569.

Discussion about the physical and biological effects of the monomolecular layer on the sea surface, including some problems related to air-sea interface modifications.

2.7 - 4.3

Gatty, O., F. C. Frank, and H. Campbell 1940

Mists and Volatile Smokes - Extra Mural Research, Porton, England, Item No. 14

1.1 - 1.2 - 1.3 - 1.4

Georgii, H. W. 1954

Einige Versuche zur experimentellen Bestimmung der Verdampfungsgeschwindigkeit kleiner Tropfchen, Zeitschr. f. Aerorol-Forschung u. Therapie, 2, 496-502.

Growth process of droplets for agricultural frost protection is investigated. The destroying processes are: sedimentation, coalescence,diffusion and evaporation. Their effect on the change in fog density in time was investigated in a hermetically closed space, using a glycol aerosol produced by a "Swingfire" machine. Separate investigation was made on the evaporation of a single droplet suspended on a cobweb filament enclosed under controlled environment. Simple theory of evaporation based on Langmuir's (1918), Whytlaw-Gray and Patterson's (1932) study is presented and comparison with experiments is made.

5.6

Gerdel, R. W. 1968

Note on the Use of Liquified Propane for Fog Dispersal at the Medford-Jackson Airport, Oregon, J. Appl. Met., 7: 1039-1040.

Liquified propane generators were used and 25 fogs were treated during 1967-68 winter. Operational minimum of 0.5 miles horizontal visibility and 200 ft. ceiling were attained in 15 of 25 treatments. In 8 cases the horizontal visibility increased from 500 to several thousand feet.

5.12 - 6.1

Gibbs, W. E. 1924

Clouds and Smokes: The Properties of Disperse Systems in Gases and Their Practical Applications. Publ. P. Blakiston's Son and Co., Philadelphia and J. & A. Churchill, London, 240 pp.

A detailed treatise on aerosols including definition of disperse systems, movement of particles, formation of aerosols and their properties, stability and physical - chemical properties of aerosols, emission and diffusion of pollutants, measurements and sampling.

Also included are 11 ref. Smoke in warfare.

1.1 - 1.2 - 1.3 - 3.1 - 3.2

Gladkova, Ye. N. and G. I. Natanson 1958

Methods of Measuring the Size of Monodisperse Fog Particles with a Radius of 0.1 to 0.5 μm (in Russian), Zhur. Fizicheskoi Khimii USSR, 32, 1160-1162 (Transl. Joint Publ. Res. Serv. New York, No. L-648-N).

Mean size of monodisperse fog particles was determined by photographing the zigzag trajectories of charged particles in an electric field (Fuchs and Petryanov 1933). An analytical derivation of the particle motion was presented. Also, a description of the experimental facility with the charge distribution on particles of polydisperse aerosol is attached.

1.2 - 1.6 - 4.4

Gockel, A. 1903

Ueber Elektrizitätszerstreuung bei nebeligem Wetter, Physik. Z., 4, 267-270.

1.6 - 4.4

Godard, L. 1959

Procédé pour déterminer les dimensions des gouttelettes de brouillard ou des nuages, Bull. Observ. Puy de Dome, 1, ' -13

The author uses a mixture of 5% gelatin and 5% collargol for the identification of the deposited droplets on a glass slide. It is possible to detect droplets having a diameter of a few tenths to a few hundreths of a micron.

1.1 - 1.2 - 1.9

Goodman, J. K. 1976

The Microstructure of California Coastal Fog and Stratus, Rep. to NSF No-76-09, Dep. of Meteorology, San Jose State University, California, September

The report contains observations on the micrometerological conditions of fogs in San Francisco area and on the microstructure of the fogs. The general synoptic situation at the fog occurrence is analyzed together with the temperature, wind and humidity measured on a 250m TV-tower. The mean drop sizes ranged from diameters 4.5 to 8.2 μm. and concentrations from 126 to 260 cm^{-3}. Liquid water content was very low (5.3×10^{-3} to $60.7 \times 10^{-3} gm^{-3}$) due to the limited collection efficiency of the impactor for large drops. AN counts were 1,200-2,000 cm^{-3} in the inversion.

1.1 - 1.2 - 1.3 - 2.2 - 2.5

Gorbatschev, S. 1938

The mechanism of the processes of formation and dispersion of fogs, Bull. Acad. Sci. URSS, Ser. Geogr. Geophys. 1, 63-71.

2.1 - 2.7

Grassl, H. 1976

A New Type of Absorption in the Atmospheric Infrared Window Due to Water Vapor Polymers. Beiträge zur Physik der Atmosphäre, 49, 225-236.

A review paper on the "continuous" absorption found in the 8-13 μ infrared window. The absorption is proportional to both water vapor amount and water vapor pressure. Old and new laboratory measurements and atmospheric measurements are reviewed. The importance of this extra absorption to atmospheric radiation transmission is discussed and calculations are shown as to its effect. Finally the probable cause of the absorption is suggested to be the water dimer. The evidence, however, is not conclusive.

4.6

Grassl, H. 1978

Possible Changes of Planetary Albedo Due to Aerosol Particles, to be published in "Advances in Atmospheric Sciences" (Elsevier). (14 typewritten pages total length).

Calculations give changes in albedo with various models for aerosol particles in cloud free areas and for changes in clouds with various complex indices of refraction and aerosol assumptions. The author concludes that it is very difficult to apply these results to the total planetary albedo (even in to size of the effect). Measurements needed are principally aerosol particle distribution, absorption coefficient of aerosol particles and histograms of the optical depth of clouds. All are needed over a variety of conditions to assess the planetary results.

1.5 - 4.6

Green, H. L. 1934

Some accurate methods of determining the number and size frequency of particles in dust. J. Ind. Hyg. 16, 29-39.

The importance of the knowledge of particle size distribution and concentration of injurious dust breathed by workers is discussed. Description of a simple sedimentation cell with which particles down to 0.2 µm in diameter can be sized is presented.

1.1 - 1.2 - 1.8

Green, H. L., and W. R. Lane 1957

Particulate Clouds: Dust, Smokes and Mist, D. Van Nostrand Co., Inc., Princton, New Jersey, 436 p. (1000 ref.)

Part I - (pp. 3-277) treats the subject from the point of view of physics and physical chemistry: definition and properties of particles; production of particles, physical characteristics of particles, optical properties, settling, coagulation, electrical charge, movement in the field of outer forces. Sampling and measurement of aerosol particle characteristics. Diffusion in the atmosphere.
Part II - (281-410) discusses health hazards, atmospheric pollution, aerosols in nature, dissipation of fog, visual range improvement and the use of particulate clouds in industry, for therapy, screening and signal smokes and in agriculture.

1.1 to 1.11 - 2.1 to 2.7 - 3.1 - 3.2

Green, H. L. 1953

Smoke. Chapter in Hermans (1953), 344-381.

Different methods of smoke generation during rapid condensing and slow condensing process are described. Different methods for particle removal and transformation such as sedimentation diffusion, coagulation (including wall losses) are mentioned. Basis of the theory of aerosol filtration (deposition of particles on fibers by interception, inertia and diffusion) are outlined. A special chapter is dedicated to the movement of smoke particles in an electric field, in thermal gradient and in sonic and supersonic field. Finally, the determination of the number and size of smoke particles is described.

1.1 - 1.2 - 1.8 - 3.1 - 3.3

Green, H. L. and W. R. Lane 1964

Particulate Clouds Dusts, Smoke and Mists, 2nd Edition, E. & F. N. Spon Ltd. 11, New Feffer Lane, E. C. 4, London, First edition in 1957

Physical properties of aerosols, coagulation, deposition, filtration. Sampling of particulates by impaction-thermal precipitator. Diffusion in the atmosphere diffusion from stacks. Industrial and environmental aspects - atmospheric pollution - aerosols in nature - cloud, fogs, haze, mist, cond., ice nuclei, visibility.

Use: Signal smoke, insecticidal smokes and screening studies.

1.1 - 1.2 - 1.4 - 1.5 - 1.6 - 1.9 - 3.1 - 3.2 - 6.1 - 6.2 - 6.4

Greenfield, S. M. 1969

Weather Modification Research; A Desire and an Approach, Rand Corp., Santa Monica, Paper 4027.

Critical remarks on the goals, methodology and organization of weather modification programs are presented.

6.1

Grimsehl, E. 1904

Künstliche Nebel. Z. physik. Unterr. 17, 221-222.

1.1 - 1.2 - 1.3 - 1.5

Hagen, D. I. 1967

Precipitation Scavenging of Submicron Particles: A Comparison of Theory with Field Results, Proceedings of the USAEC, Meteor. Inform. Meeting, Sept. 11-14, 1967, AECL-2787, ed. by C. N. Manson, pp. 541-552, Chalk River, Ontario.

4.1 - 5.9

Hänel, G. 1976

Discussion of Artificial Fog Modification NATO, AGARD, Conf. Proc. No. 192, pp. 4-1-4-3.4.

4.1 - 4.2 - 5.1

Hänel, G. 1976

The Single-Scattering Albedo of Atmospheric Aerosol Particles as a Function of Relative Humidity. J. Atmos. Sci., 1120-1124.

Mie scattering theory is used to calculate the single-scattering albedo (1-ratio of absorption coefficient to extinction coefficient) for 3 aerosol models: maritime, urban and clean air aerosol (at specific locations and times). The results show that above a relative humidity of 60% the effect of relative humidity or the albedo should not be neglected. Results are tabulated for wavelengths from 0.55 μm to 12 μm.

4.3 - 4.6

Hann, J., and W. Köppen: Editor 1889

Einfluss der Lufterschütterungen auf Nebel und Regen, Met. Zeitschr. 6, 318.

Ch. Ed. Guillaume observed that the use of canoon granade explosives contributed to the fog dispersion. Sept. 25, 1888 in Switzerland the artilerie division 16 canoon (Morser-Sabiesse) with 500 gr. granades fired. After 5 minutes one observed the fog in the valley was dispersed.

5.7

Hanna, S. R. 1978

A review of the influence of new boundary layer results on diffusion prediction techniques, in the Proc. WMO Symposium on Boundary Layer Physics Applied to Specific Problems of Air Pollution, Norrköping WMO, No. 510, Geneva, 119-126.

The important difference in Lagrangian and Eulerian concept of turbulent description with regard to the modeling of atmospheric diffusion is made. Mainly for continuous source diffusion the distinction is very important. The estimates of the vertical eddy diffusivity and its changes during the daytime are made.

2.5 - 2.6 - 3.1 - 3.2

Heiser, L. 1975

La dissipation des brouillards froids sur les aéroports, La Météorologie, Num. Spec. Aviation et Météorologie, Nov. 35-40.

The dissipation of supercooled fogs with the aid of a liquified gas (propane) is described and some features outlined. The installation and some experiments at the Orly Airport are described.

5.12

Henderson, T. J. 1968

Commercial Prospects and Problems for Weather Modification Activities, (in Taubenfeld H. J.: Weather Modification and the Land, Dobbs Ferry, N. Y. Oceans Publications Inc. p. 65-75).

Commercial funding shows a significant decrease over the 1950's, but there is a calling upon commercial organizations for assistance. Airlines are heavily involved in fog dissipation.

6.1

Hendricks, C. D. 1973

"Charging Macroscopic Particles", (chap. 4, in "Electrostatics and Its Application", ed. by A. D. Moore, New York, John Wiley & Sons, 57-85

1.6 - 4.4

Hendricks, C. D. 1962

Charged Droplet Experiments. J. Coll. Sci. 17, 249-59.

1.6 - 4.4

Hertelendy, A. 1953

Contre le brouillard, Aviatika, Budapest, 9, 146-148.

4.1

Hess, W. N. 1974

Weather and Climate Modification, John Wiley & Sons, Inc. New York, 842 pp.

Survey about projects, exper. and results.

6.1

Hicks, J. R. 1966

Improving Visibility During Periods of Supercooled Fog Hanover, N. H., U. S. Army Cold Regions Res. Eng. Lab., Tech. Rep. No. 181, 4°, pp. 35.

5.12

Hicks, J. R. 1965

Experiments on the Dissipation of Warm Fog by Helicopter Induced Air Exchange Over Thule A B, Greenland, U. S. Army Cold Regions Res. and Engineering Lab., Special Rep. 87, Hanover, N. H., 7 pp.

5.4 - 5.5

Hicks, J. R. 1967

Fog Dispersal Experiments Using Propane at Walla Walla, Washington, U. S. Army Cold Regions Res. Eng. Lab. Tech. Rep. No. 198, 4°, pp. 11.

5.12

Hicks, J. R., and R. C. Rice 1977

Laboratory Studies of Compressed Air Seeding of Supercooled Fog, Hauser, N. H., U. S. Army Col Reg. Res. Eng. Lab. Spec. Rep. 77-12, pp. 19, 3 ref.

5.12

Hilsenrod, A. 1965

Test of Patent Technique for Dissipating Fog and Low Clouds, U. S. Federal Aviation Agency, SRDS Report RD-65-54, June.

The patent technique: liquid CO_2 and methylalcohol from a fire extinguisher were used in order to dissipate fog. No positive results were found.

6.'

Hidy, G. M., and J. R. Brock 1970

The Dynamics of Aerocoloidal System, Pergamon Press, Oxford, 379 pp.

The monograph discusses in detail the theory of the motion of aerosol particles in a continuum, free molecular and transitional regime. The transfer processes include diffusion and dispersion of aerosol particles aerosol generation and desintegration, growth of nuclei by condensation and coagulation of particulates. The book contains 446 literary references.

1.1 - 1.2 - 1.4 - 4.1 - 5.6

Hindman, E. E. 1966

Theoretical Investigation of Techniques using Dry Ice for the *Dissipation of Supercooled Fogs -4°C and Warmer*, Bull. Amer. Met. Soc. 47, 445-449.

The author discusses the methods of the application of the dry ice for fog seeding. The rough calculations show the possibilities of this method and different techniques are mentioned such as the dispersion of CO_2 from balloons, generators on the ground and from the aircraft. All methods are limited to temperatures lower than -1°C.

5.12

Hindman, E. E., and R. S. Clark 1972

Evaluation of Warm-Fog Abatement Chemicals, Washington D.C. FAA. Syst. Res. Dev. Serv. Rep. No. FAA-RD-72-21, Final Rep. 4°, pp. 31.

Hobbs, P. V. 1968

Scientific Basis, Techniques, and Results of Cloud Modification, Weather Modification: Science and Public Policy Seattle, Wash., Univ. Press, 30-42.

The author outlines problems related to the weather modification program. From the survey of the techniques currently applied and comparison with the stand of cloud physics conclusions on the perspectives and development of cloud modification are made.

6.1

Hindman, II, E. E., and O. E. R. Heimdahl 1977

Sub-micron haze droplets and their influence on visibility in fog, *6th Confer. on Planned and Inadvertent Weather Modification*, Champain-Urbana, Illinois, AMS, Boston, October 1977, 177-179.

Results of a preliminary study of the influence of small sub-micron haze droplets is presented. The contribution of these droplets to the visibility reduction in coastal fogs at Trinidad, Cal. is insignificant. However, in post-Santa Ana fogs at San Diego, this influence might be significant and might retard the improvement in visibility after fog seeding with giant hygroscopic nuclei.

1.7 - 2.2

Hocking, L. M. 1959

The Collision Efficiency of Small Drops, Quart. J. Roy. Met. Soc., 85, 44-50.

5.1 - 5.9

Hocking, L. M. and P. R. Jonas 1970

The Collision Efficiency of Small Drops, Quart. J. Roy. Met. Soc. 96, 722-729.

4.1 - 5.9

Hohler, D. J. 1966

An Analytical Method of Determining General Downward Flow Field Parameters for V/STOL Aircraft, AF APL-TR-66-90 Air Force Aero Propulsion Lab., Wright Patterson AFB, Ohio, 61 pp.

5.4 - 5.5

Holzman, B. 1943

The Influence of Stability on Evaporation, Ann. N. Y. Acad. Sci. 44, 13-18.

2.5

Horvath, H. and G. Presle 1978

Determination of the atmospheric extinction coefficient by measurement of distant contrasts, Appl. Optics, 17, 1303-1304.

Discussion of the measurement of the extinction coefficient with the aid of determination of distant contrast is made. The authors present a description of the apparatus with which conditions in the free atmosphere are simulated.

1.5 - 4.6

Hougton, H. G., and W. H. Radford 1938

On the Local Dissipation of Natural Fog, Pap. in Phys. Oceanography and Meteorology, MIT, Woods Hole Oceanogr. Institution, Cambridge & Woods Hole, Mas., October, 5-63.

The authors mention the different ways how the fog can be cleared. They divide the methods into two big groups: 1) methods based on the physical removal of drops from th air, 2) particles are evaporated in the air. They chose the method of fog seeding by $CaCl_2$. Conclusion: Fog must be dispersed at a rate 2,000 m^3 per sec. in a space 500-1000 long, 30-50 m wide and 10-20 m high. For reaching that spraying of 4 to 5 liters of saturated soluti n per second was used.

4.1 - 4.3

International Civil Aviation Organization 1968

U. S. Fog Dispersal Tests Prove Successful, I.C.A.O., Bull., 23, No. 8, 14-16.

5.12 - 6.1

Humphreys, W. J. 1926

Fogs and clouds, London, Bailliere, Tindall & Coz, 104

2.1 - 2.7

Israel, H. and F. Kasten 1959

Die Sichtweite im Nebel und die Möglichkeit ihrer künstlichen Beeinflussung, Forsch. Ber. Wirtsch. Verkehrs-Ministeriums, Nordheim-Westfalen, Nr. 640, Westdeutsch. Verlag, Köln, 76 pp.

The different techniques are discussed (evaporation, mechan. deposition, coalescence). The visual range can improve by using the water explosive techniques.

5.2 - 5.5

Jarvis, N. L. 1972

Effect of Various Salts on the Surface Potential of the Water-Air Interface. J. Geophys. Res. 77, 5177-5182.

1.6 - 3.4 - 4.4

Jiusto, J. E. 1964

Project Fog Drops: Investigation of Warm Fog Properties and Fog Modification Concepts, Washington, NASA, Contractor Rep. CR-72, 40, pp. 54.

4.1 - 4.2 - 4.3 - 5.6 - 6.1

Jiusto, J. E. 1964

Some Principles of Fog Modification with Hygroscopic Nuclei U. S. NASA, Spec. Rep. SP-212: 24-39.

Improvement of visibility in a fog using NaCl particles is discussed. The recommended size of larger saline drops for radiation fogs are r = 5-10μ (in concentration of few mgm^{-3}). Corrosion problems accompanying the seeding with hygroscopic substances are mentioned.

4.3

Jiusto, J. E., R. J. Pilié, and W. C. Kocmond 1968

Fog Modification with Giant Hygroscopic Nuclei, J. Appl. Met., 7: 860-869.

Fog modification studies in the 600 m^3 chamber where the NaCl particles were used are described. An increasing visibility (3-10x) using 1,7 $mg\ m^{-3}$ was observed. Use of NaCl particles leads not to a substantial decrease in humidity (<1%), but nevertheless can lead to the evaporation of some of the droplets.

4.3 - 5.6

Johansen, D. B., E. H. Barker, and P. R. Lowe — 1974

Using Helicopters to Clear Fog: A Numerical Study, ENVPREDRSCHFAC, Tech. Paper No. 2-74, Monterey, 38 pp.

5.5

Jonas, P. R. — 1972

The collision efficiency of small drops, Quart. J. Roy. Met. Soc., 98, 681-683.

4.1 - 5.9

Junge, C. E. — 1958

Methods of Artificial Fog Dispersal and Their Evaluation, AFCRC-TN-58-476, Bedford, Mass., AFCRC Air Force Surv. Geophys. No. 105, 4°, pp. 19, 25 ref.

6.1

Junge, C. E. — 1963

Air Chemistry and Radioactivity, Academic Press, New York & London, 382 pp.

A monograph on the properties of atmospheric gases and particulates. Included are: Particulates and atmospheric radioactivity, size distribution and concentration of particulates, chemistry of precipitation and the role of air pollution in air chemistry. Each of the five chapters includes an extended reference list.

1.1 to 1.7

Kahan, A. M. 1968

Weather Modification Effects on Man's Environment, Western Resources Conf., 9th., Univ. of Colorado, July 5-7, 1967, Boulder, Univ. of Col. Press.

General survey on weather modification is presented. Among other projects fog experiments on Orly Airport, France are mentioned.

6.1

Katheder, F. 1937

Auflösung einer Bodennebeldecke durch ein startendes Flugzeug. Z. angew. Meteorol. 54, 61-63.

5.5

Katchurin, L. G. 1973

Fizicheskie osnovy vozdeistvia na atmosfernye protsessy, Gidrometeoizdat, Leningrad, 366 pp.

"The Physical Elements of Acting on Atmospheric Processes"

The chapter 5 of this monograph is dedicated to the artificial dispersion and generation of fogs. In more details are discussed the visibility in fog, the use of FIDO burner systems, the dynamical methods, carbon black method, hygroscopic substance seeding, acoustical method, electric charging, application of laser beam, the use of surfactants.

2.1 - 2.7 - 5.1 to 5.12

Kimball, H. H. 1973

The Meteorological Aspects of the Smoke Problem, Univ. of Pittsburgh, Pittsburgh, Pa., 51 pp.

2.3 - 2.5

Kleber, B. E., and D. Birdsell 1966

The Chemical Warfare Service; chemicals in combat, Office of the Chief of Military History, U. S. Army, Vol. 6, 697 pp. Bibliograph. note p. 659-663: Smoke screens -

1.3

Knollenberg, R. C. 1965

Urea as an ice nucleant for supercooled clouds, Tech. Note No. 29, Cloud Phys. Labor., Univ. Chicago, 15 pp.

The temperature of solution of the urea is 60°C/g and one can easily freeze the drops which reached the positive temperature of +60C. The author expresses the hypothesis that epitaxial growth might play a decisive role.

5.:2

Klett, J. D. and M. H. Davis 1973

Theoretical Collision Efficiencies of Cloud Droplets at Small Reynolds Number, J. Atmos. Sci. 30, 107-117.

4.1 - 5.9

Kocmond, W. C. 1968

Investigation of Warm Fog Properties and Fog Modification Concepts, Cornell Aeron. Lb. Report, RM-1788-P-18, Jan. 15, 10 p.

Includes: 1) Theoretical modeling of fog by seeding with hygroscopic nuclei, 2) Climatic survey of fog frequency at Buffalo, 3) Large experiments with NaCl particles.

4.3 - 5.6

Kocmond, W. C., and J. E. Jiusto 1968

Investigation Of Warm Fog Properties for Modification Concepts, U. S. NASA, Contractor Rep. CR-1071, p. 56.

The possibility of fog dispersion by seeding with micron size salt particles (NaCl) increasing the visibility by a factor 3 to 10 x with as little 1.7 mg of NaCl m^{-3} is discussed on the basis of the cloud chamber (600 m^3) study.

4.3 - 5.6

Kocmond, W. C., R. J. Pilié and J. E. Jiusto 1968

Warm Fog Suppression with Giant Hygroscopic Nuclei, Proc. Int. Conf. on Cloud Physics, Univ. of Toronto, Aug., 694-699

Program for 600m^3 cloud chamber is outlined: NaCl particles of controlled size $4\mu m<d<10\mu m$ were selected. Droplet samples were taken by gelatin coated slides, (on the 2mm wide strip at 30m sec^{-1} velocity). Seeding quantities between 4mgm^{-3} to 200mgm^{-3} to which corresponded the maximum visibility improvement factor 2.8 to 13, were the most effective.

4.3

Kocmond, W. C. 1969

Dissipation of Natural Fog in the Atmosphere, U. S. NASA, Spec. Public. 212, 57-74.

The description of Cornell Laboratory fog experiments on the airport Elmira, N. Y. using hygroscopic particles is presented.

4.3 - 5.6 - 6.1

Kocmond, W. C., and R. J. Pilié 1969

Investigation of Warm Fog Properties and Fog Modification Concepts, Cornell Aeron. Lab., Buffalo, N. Y., CAL rep. RM-1788-P-22, Feb. 15, 18 p.

A detailed description of the previous experiments in laboratory and at the airport Elmira with NaCl seeding of warm fog is presented. Fog characteristics are attached: 700 lbs of NaCl powder (10-30µ in diameter) produced fully cleared areas for about 30 min. The visibility improvement was in 60% caused by the decrease of the fog liquid water caused by precipitation of the large saline droplets after seeding.

4.3 - 5.6 - 6.1

Kocmond, W. C. 1969

Laboratory Experiments With Seeding Agents Other Than NaCl, U. S. NASA, Spec. Public. SP-212, 86-96.

NaCl, urea and certain phosphates are effective in promoting fog dispersion. Polyelectrolytes are ineffective as seeding agents.

4.3 - 5.6

Kocmond, W. C., R. J. Pilié, W. J. Eadie, E. G. Mack and R. P. Leonard 1971

Investigation of Warm Fog Properties and Fog Modification Concepts, Washington, NASA, Contractor Rep. CR-1731, 4°, pp. 102, 16 ref.

The report describes experiments which were performed in warm fogs at the Elmira airport to determine the potential of different seeding techniques. Urea, sodium chloride and sodium phosphate were tested. The most effective was the aerial seeding. The most disturbing factor was the simulation of the seeding effects; included also terms of atmospheric turbulent diffusion. One four week seeding was conducted at the Seattle-Tacoma Airport. No firm conclusions were drawn with regard to the efficiencies of different seeding substances.

4.3 - 5.6 - 6.1

Kocmond, W. C., W. D. Garrett and E. J. Mack 1972

Modification of Laboratory Fog with Organic Surface Films, J. Geophys. Res., <u>77</u>, 3221-3231.

Experiments performed in a 600 m^3 expansion chamber showed an effect of cetylalcohol layer on the instability of an artificial fog. However, this change was not permanent and the experiments indicate that the retardation of evaporation on treated nuclei did not significantly change the visibility for a longer time period.

4.3

Koenig, L. R. 1969

Numerical Experiments Pertaining to Warm-Fog Suppression, RAND Corp. Mem. RM-615PR, Oct.

The author uses microstructural model (based on Murray's 1967 formula and Teten's formula, Raoult's correction and Kelvin's correction). Fog model is based on: constant pressure: 1000mb - temperature decrease with time. Droplet fallout was incorporated into the model (based on Gunn & Kinzer 1949 formulas). Numerical model was tested on the experiments by Cornel lab. (8mg/m^3 NaCl, 17 size classes max. frequency at 4.0 - 5.0μm in dia.); adiabatic cooling was 4°C/hour (or 2°/hour). Concentrations of particles chosen were between 250 to 10,000 particles/cm^3. Result: A fog formed in a "clean air" is more susceptible to artificial modification than fog formed in a "dirty" atmosphere. After the largest particles will fall out, the visibility will improve.

4.3

Kokhanovich, M. M., V. G. Morachevskii and
E. K. Fedorov 1965

Nauchnye problemy upravleniia pogody, Gidrometeoizdat, Leningrad, 64 pp.

A translation of the USA "Report of the panel on weather and climate modification, Committee on Atmospheric Sciences of the Nat. Academy of Sciences and Nat. Research Council", Washington, 1964, under the title "Scientific Problems of Weather Modification". In the introduction academician Fedorov mentioned the historical development of similar efforts in the USSR since 1930. The history of the "Institute of the Artificial Rain" founded in 1935 is outlined and further continuation and extension of the work after World War II described. The activities include also dispersion of fogs.

6.1

Kolosov, M. A. 1969

Sviaz koefitsienta oslableniia intensivnosti lazernogo izlucheniia s vodnostiu isskustvennykh tumanov, Izv. AN SSSR, Fiz. Atmos. i Okeana, 5, 642-646.

At wavelengths of 0.63 to 1.15 and 1.1? to 3.39 μm the coefficient of attenuation increased linearly with increasing water content.

1.5 - 4.6

Korb, G. and F. Mueller 1962

Theoretical Investigation on Energy Gain by Absorption of Solar Radiation in Clouds. Final Tech. Rept. Contract DA 91-591-EUC-1612, Met. Institut München, 185.

2.4

Kornfeld, P. 1970

Some Numerical Experiments for Warm Fog Clearing by Seeding with *Hygroscopic Nuclei*, J. Appl. Met. 9: 459-463.

Numerical study of warm fog clearing by seeding with hygroscopic nuclei: The new distribution of fog drops (after 60 or 100 sec. after seeding) and visibility improvements are presented.

4.3 - 5.6

Kraemer, H. F., and H. F. Johnstone 1955

Collection of Aerosol Particles in Presence of Electrostatic Fields, Ind. Engin. Che., 47, 2426-2434.

1.6 - 4.4 - 5.6

Krasikov, P. N. and V. Ja. Nikandrov 1963

Investigation of Means of Artificial Action on Clouds and Fogs. Leningrad, Glav. Gidromet. Sluzh. Sov. Min. SSSR, Works All Union Sci. Council, 5, Physics Free Atmos., 129-137.

6.1

Kraght, P. E. 1969

Warm fog modification. Shell Aviation News, London No. 375: 16-23.

The experiments with the aim to disperse the fogs are described. In warm fog case are mentioned all main performed experiments (Cornell Lab., Bollay World Weather Inc., Meteorology Research, Altadena) and indicated the limited possibilities of using the hygroscopic substances. The design of a ground basod dispersing machine, turbulent diffusion of seeding agents and other problems are mentioned.

4.2 - 5.6 - 6.1

Kumai, M. 1969

Fog Modification Studies on the Greenland Ice Cap U. S. Cold Regions Res. and Engin. Lab., Hanover, N. H. Res. Rep. 258, March.

Fog modification by propane and dry ice seeding at very low concentration of atmospheric pollution was attempted. The shapes of crystals after propane and dry ice seeding are the same. The nuclei in supercooled fog drops were sea salts and in ice crystals many minerals were found.

5.12

Kumai, M. 1969

Formation and Reduction of Ice Fog., U. S. Cold Regions Research and Engineering Lab., Hanover, N. H. Res. Rep. 235, March, 21 p.

Ice fogs and ice crystals are discussed in details. The analysis of the Alaska ice fogs and the processes leading to their origin are presented.

6.1

Kumai, M., and J. G. Russell 1969

Attenuation and Backscattering of Infrared Radiation by Ice Fog and Water Fog, U. S. Cold Regions Res. and Engin. Lab., Hanover, N. H., Res. Rep. 264, April 7 p.

Ice-fog crystals consisting of many spherical and some hexagonal plates and columns at -40°C in Fairbanks, Alaska were used for calculation of attenuation and back scattering for λ = 2,2; 2,7; 4,5; 5.75; 9,7; 10.9 μ using Mie theory. The minimum attenuation of ice fog were found to be at $\lambda = 9.7\mu$. For fog drops minimum was at $\lambda = 10.9$.

1.5 - 4.6

Kunkel, B. A. 1963

On the seeding of warm fog with water, Bull. Amer. Me.. Soc. 44, No. 11, p. 728.

The study deals with the calculation of the distribution of the sizes of fog droplets. Also is discussed the effect of the electric charge of drops.

1.2 - 4.1 - 4.4

Kunkel, B. A. 1973

A Statistical Approach to Evaluating Fog Dispersal Operations, J. Appl. Met. 12, 883 - 887

Aerial seeding of fogs was considered in the case that the seeding might last for 3 hrs. or less and a statistical method for evaluating the seeding results is proposed. The basis for this is the consideration of a natural trend of fog dissipation in a certain area (Base Vandenberg) which helps to evaluate more correctly the effect of artificial interference.

6.1

Kunkel, B. A., B. A. Silverman, and A. I. Weinstein 1973

Thermal and Chemical Dissipation - Results of Field Experiments at Vandenberg AFB, California during July 1972, AFCRL-TR-73-0502, Bedford, Mass. AF CRL Envir. Res. Pap. No. 454, 1973, 4°, pp. 53.

5.1 - 5.6 - 6.1

Kunkel, B. A., B. A. Silverman and A. I. Weinstein 1974

Evaluation of some Thermal Fog Dispersal Experiments, J. Appl. Met. 13: 667-675.

The experiments with warm cloud dissipation by means of passive burners (of the type FIDO) at Vandenberg AFB, Cal. in 1972 are described. Four lines of propane burners were oriented perpendicularly to the prevailing wind direction. The influence of wind speed, heat output and mean temperature on the visibility in the fog were investigated. The program documented visibility improvements.

5.1 - 5.2

Kunkel, B. A. 1975

Heat and Thrust Requirements of a Thermal Fog Dispersal System, AFCRL-TR-75-0472, Bedford, Mass., Surv. Geoph. No. 322, 43 pp. 8 ref.

5.2

Kunkel, B. A. 1977

The design of a warm fog disperal system, 6th Confer. on Planned and Inadvertent Weather Modification, Champaign-Urbana, Illinois, AMS, Boston, October 1977, 174-176.

Thermokinetic system for fog dispersion is described. The goal is to increase the ambient temerature to 2°-3°C above the environment. The important point is the position of heat plume, mainly at crosswind situation. Two main categories were chosen: 1) clearing of a space of 60m high x 150m wide x 800m and 2) 30m x 150 x 400m. 3° glide slope is requested. Combustors (the total number 34 combustors along two 600m lines spaced 155m apart) will be used and 259 gallons per minute consumption of fuel is anticipated. Full scale experiments at Otis AFB are prepared.

5.2 - 6.1

Laikhtman, D. L. 1970

Fizika pogranichnogo sloia atmosfery, Gidrometeoizdat, Leningrad.

The book surveys the "Physics of the Atmospheric Boundary Layer" and is based mainly on the author's contribution to their subject. A more general term for the exchange coefficient is deduced and applied to the models of turbulent exchange in the boundary layer. Some applications for air pollution and evaporation are mentioned. A useful literature survey mainly of Russian contributions to the subject is attached.

2.1 to 2.6

Langmuir, I. 1948

The Production of Rain by Chain Reaction in Cumulus Clouds at Temperatures above Freezing, *J. Meteor.* 5, 175-192.

The basic theory of a chain process of raindrop formation inside of a convection cloud. The author mentions the collision efficiencies for the differently sized drops, which justify the rain formation in warm clouds.

4.1 - 5.9

Ladenburg, R. 1930

Untersuchungen uber die physikalischen Vorgänge bei der sogenannten Gasreinigung, Ann. der Physik, 4, 863-897.

1.6 - 4.4

Law, S. E. and H. D. Bowen 1966

Charging Liquid Spray by Electrostatic Induction. Amer. Soc. Agr. Engin., Trans. 9. 501-506.

1.6 - 4.4

Leonard, P. 1904

The measurement and utilization of fog, Month. Weath. Rev., 32, 169-170.

1.1 - 1.2 - 1.5

Leonov, L. F., P. S. Prokhorov, and *I. A. Zolotaryov* 1969

Experimental Study of the Possibility of Passivating the Hygroscopic Nuclei by Means of Cetyl Alcohol Vapors, Int. Conf. on Condens. and Ice Nuclei, 7th, Prague - Vienna, Sept. 18-24, 1969 Proceedings Prague - Academia.

The use of aerosol chamber studies for passivation of hygroscopic salts and drops is described. The authors obtained a positive result in the case of NaCl particles passivated by cetyl alcohol layer.

1.4 - 4.3

Lettau, *H.* 1939

Atmosphärische Turbulenz, Akad. Verlag, Leipzig, Also J. W. Edwards, Ann Arbor, Mich., 1944.

The author deals with the subject of atmospheric turbulence from the point of view of a meteorologist or a geophysicist. Mathematical formulation of the turbulent and exchange phenomena forms a basis for a comparison with the measurements in nature. A useful survey of the older literature is attached.

2.5 - 2.6

Lettau, H. and B. Davidson 1957

Exploring the Atmosphere's First Mile, *Vol. 1 and 2*, Pergamon Press, *New York*.

The publications represent a collection of contributions to the theoretical and experimental investigations of the atmospheric boundary layer. The first volume contains more theoretical and methodological studies, the second volume is dedicated to the measurements.

2.5 - 2.6

Levin. L. M. 1961

Issledovania po fizike grubodispersnykh aerosolei, Izd. AN SSSR, Moskva, 267 pp.

"Investigations into the physics of coarse aerosols" is a monograph dedicated mainly to the deposition of coarse aerosol particles through impaction on substrates and to the theory of electrostatic coagulation. The theoretical models are applied to the collection of cloud droplets in impactors. A mathematical basis of the gamma-distribution of particle sizes is presented.

1.2 - 1.6 - 1.9 - 4.1

Levin, L. M. and Ju. S. Sedunuv 1965

O turbulentno-gravitatsionnoi koagulatsii oblachnykh kapel, Doklady AN SSSR, 164, 552-555.

Basic equations are deduced for the interaction between the cloud droplets in a turbulent field. Turbulent diffusion cannot be responsible for the growth of drops with $r > 18\ \mu$.

4.1 - 5.9

Lin, C. L., and S. L. Lee 1975

Collision Efficiency of Water Drops in the Atmosphere, J. Atmos. Sci., 32, 1412-1418.

The calculation of the collision efficiency of two (rigid) drops is based on the solution of the equations for viscous flow including the inertial term. The results are compared with similar calculations by other investigators and with several experiments. They show a fair agreement.

4.1 - 5.9

Lininger, R. L., and H. S. Appleman 1966

Project Cold Fog I., Washington, Air Weath. Serv., Tech. Rep. 188, 65-70.

5.12

Little, A. D. (B. Vonnegut) 1953

Warm Fog and Stratus Cloud Dissipation, Quart. Rep. No. 1, 2, 3, and 4, Contract No. DA-36-039 SC-42585, Cambridge, Mass., Jan., April, July, Oct., pp. 3, 4, 3 and 3.

Several possibilities how to disperse a fog have been considered. Finally, the decision has been made to attack the problem by the use of electrostatic techniques. Several generators of electrostatic charges have been considered. Preliminary experiments indicated that the charge generation might be sufficient.

4.4 - 5.8

Little, A. D. (B. Vonnegut) 1954

Warm Fog and Stratus Cloud Dissipation, Quart. Rep. No. 5, 6, 7, and 8, Contract No. DA-36-039 SC-64569, Cambridge, Mass., Jan., Apr., June, Sept., pp. 44, 55.

No conclusion has been reached on the efficiency of the space charge generator. A propeller shroud has been used for blowing the cloudy air into the generator. The oil was used to produce the highly charged aerosol. A low pressure injection was selected. Better sprayer and aerosol charger has been used. A corona prevention device was found.

4.4 - 5.8

Little, A. D. (B. Vonnegut) 1955

Warm Fog and Stratus Cloud Dissipation, Quart. Rep. No. 1 to Signal Corps, Contract No. DA-36-039 SC-64569, 7 p., Cambridge, Mass., April.

The experiments have been performed with "Fine-wire space-charge generator": 800 foot-long; 0.005 inch stainless steel wire is stretched between poles at a height of 12 feet. The wire can be maintained at either positive or negative polarity at potentials up to 35 kV. Tests have shown that the electric fields were 10 to 20 V per cm (normal atmosph. field is 1 V cm^{-1}).

4.4 - 5.8

Little, A. D. (B. Vonnegut) 1955

Warm Fog and Stratus Cloud Dissipation, Quart. Rep. No. 2 to Signal Corps Supply Agency, Contract No. DA-36-039 SC-64569, August, 42 pp.

Further progress on the study of the influence of an electrostatic field on clearing of fog is described: "Fine wire" technique, new design of highly charged aerosols, methods of monitoring fog concentration and droplet size distribution are discussed. The author managed to have 1,000 elem. charges in cm^3 and for a short time 50,000 cm^{-3} (which is 1/20 of the concentration required by Pauthenier). Experiments with "heat pump" have exploited the drying of the foggy air with refrigerating coils.

4.4 - 5.8

Little, A. D. (B. Vonnegut) 1955

Warm Fog and Stratus Cloud Dissipation, Quart. Rep. No. 3 to Signal Corps Supply Agency, Contract No. DA-36-039 SC-64569, Cambridge, Mass., Dec. 7 p.

A description with the "fine wire technique" on the Mt. Washington is presented. The generator charged the wire approximately to 20 kV and the current that flowed by corona was of the order to 200 or 300 μA. The outcome of these experiments is questionable, which can be partly explained by the high wind velocities which prevailed (40 miles per hour).

4.4 - 5.8

Little, A. D. (B. Vonnegut) 1955

Warm Fog and Stratus Cloud Dissipation, Final Rep. to Signal Corps Supply Agency, Contract No. DA-36-039 SC-4258J, Cambridge, Mass., March 21.

The description of the program under the contract is presented. Two space charge generators were designed (weak field over large area). Tests have shown that either type of generator can reverse the normal earth's field for distances of a mile or more. The experiments included methods for smoke and fog generation (oil generator sends the particles with r = 0.01 μm through an array of fine wires at about 25 kV).

4.4 - 5.8

Little, A. D. (B. Vonnegut) 1956

Warm Fog and Stratus Cloud Dissipation, Contract No. DA-36-039-SC-64569, Final Rep., Cambridge, pp. 85.

Main emphasis is put on electrical methods, but the effectiveness and cost of other methods are assessed.

1.6 - 4.4 - 5.8

Little, A. D. (B. Vonnegut) 1965

Warm Fog and Stratus Cloud Dissipation, Final Rep. to Signal Corps, Contract No. DA-36-039 SC-64569.

Various possible investigation techniques for fog and cloud dispersion have been investigated. The main attention has been paid to the clearing of fogs in the electric field by introduction of charged droplets. No conclusions can be drawn from the laboratory and field experiments. A method of drying out the cloud droplets by the deposition on refrigeration coil has been investigated; also, the absorption of solar radiation on droplets has been investigated. No simple method excels for field application.

4.1 - 4.2 - 5.3

London, Commonwealth Air Transport Council 1964

French Experiments in Fog Dispersion. London, Comm. Air Trans. Council Newsletter, No. 60, p. 18.

6.1

London, House of Commons 1961

Airfields (Fog Dispersal). London, House of Commons, Parliamentary Debates (Hansard), 637, No. 83, Col. 122-123.

4.3 - 5.1 - 5.6 - 5.12 - 6.1

Ludwig, F. L., and E. Robinson 1969

Condensation Nuclei and Aerosol Populations Related to Fog Formation, Standard Res. Inst. Menlo Park, Cal., Contract DAHC04-67-C-0059, Final Rep., Dec. 53 p.

Physical and chemical properties of fogs in San Francisco are considered. Fog formation process is discussed.

2.1 to 2.6

Lukow, T. E. and J. R. Hicks 1974

Laboratory Studies of Cold Fog Dispersal by Compressed Air, U. S. Cold Regions Research and Engineering Laboratory, Hanover, Res. Rep. 327, Dec., 12 p.

ıe authors describe two compressed air systems for glaciating supercooled clouds in the laboratory conditions. he fast expanding air was most efficient at 27 psig, producing an average of 5.2×10^3 ice crystals/cm^3 of air. The second system used continuous air expansion with a maximum of 2.5×10^3 crystals/cm^3 of air at 27 psig.

5.12 - 6.1

MacDonald, G. J. F. 1968

Evaluation of Weather Modification *Field* Tests (in Fleagle R. C.: Weather modification: Science and Public Policy, Seattle, Wash., Univ. of Wash. Press, 43-55.

The author concerns himself with whether we can really modify any weather element to a useful degree. Everything should be done to insure that substantial amounts of federal funds to be made available will be spent on priming down more conclusively the actual potential for useful modification of atmospheric processes.

:.1

Mack, E. J., U. Katz and J. Y Yang 1975

Reduced Data from Calspan's Participation in the USNS Hayes Cruise Off the Coast of Nova Scotia, in the "Marine Fog Cruise, USNS Hayes", ONR, Washington, July-August.

A detailed investigation of the marine fog microstructure has been made during the cruise of the Navy research vessel. Liquid water contents in fogs and haze ranged from 0.005 to 0.489 gm^{-3} and the mean drop radii varied between 4.1 and 10.7 µm. Also, the termperature, dew point, concentration and activity of CCN were measured.

1.1 - 1.2 - 1.3 - 2.1 - 2.2

Machothin, L. G. and W. A. Soloviev 1961

Die Elektrizität des Nebels, Zeitschr. f. Meteor. 15, 192-198.

The description of the electrical properties of the fog droplets. The instrument is described for the measurement of fog droplets and of their electrical charges. The small droplets showed much higher charges and the large one much smaller than those one would expect from the theoretical calculation.

1.6 - 4.4

Magono, et al 1963

An Experiment on Fog Dispersion by the Use of Downward Air Current caused by the Fall of Water Drops, J. Appl. Met. 2, 484-493; Comment by Plank, V. G. and reply, J. Appl. Met. 3, (1964), 213-214.

5.4

Magono, C., K. Kikuchi, T. Nakamura, and T. Kimura 1964

An experiment on fog dispersion by the use of downward air current caused by the fall of water drops, J. Appl. Meteor., 2, 484-493.

The water was dispersed from the helicopter above the layer of cloud or fog (100 m). If the drops are sufficiently great, they cause a downdraft and an intense dissipation of the thin layer of fog. The photographs are not very convincing.

4.1 - 5.9 - 6.1

Maguet, M., and R. Serpolay 1973

Action de l' acide alginique et de quelques-uns de ses derivés sur les brouillards de laboratoire, J. Res. Atmos. 7, 83-90.

The authors discuss the properties and behavior of the sodium alginate which was used for clearing the fogs in the laboratory. Several experiments have been carried out with the gravimetric method and in a cloud chamber which stress the importance ? the hydroxyles in the sorption of the water vapor and suggest the application of a salified alginic compound.

1.6 - 4.4

Magono C. 1972

A Warm Fog Dissipation Experiment Utilizing Burning Propane Gas, J. Res. Atm., VI, Memorial Henri Dessens, 343 - 365

Chitose Airport in Hokkaido in July 1963 was chosen for burning of 2.5 tone of propane gas in 5 min. in order to obtain 3.0×10^{10} cal for warming the air of $2.5 \times 10^7 m^3$. 100 burners were heated on a strip of 500m at advection fog from Pacific Ocean at a mean temperature 12 to 15°C and wind speed between 0 to 3m/sec; air was warmer after burning of propane of 0.5°C, R. H. decreased by several percent. The horizontal visibility was improved twice the original, mainly from 100 - 400m to 250 - 800m during experiments. The efficiency was much higher when the wind direction was parallel the runway comparing it with the direction across it. The estimated cost for burner system and installation would be one million dollars.

5.1

Malone, T. F. 1966

Weather and Climate Modifications, Problems and Prospects, Nat. Academy of Sci., Nat. Res. Council, Vol.1, Summary and Recommendations, 1966, 28 p., Vol. II. Research and Development, 200 p.

: e findings of a group of scientists are summarized. S tuation with the clearing of fogs can be characterized i the following way: supercooled fogs - progress has been found while seeding with dry ice, AgI and propane; warm fogs - no substantial progress when fumes were used, heated air, $CaCl_2$ etc.

5.12 - 6.1

Marloh, J. 1906

Über die Wassermengen, welche Sträucher und Bäume aus treibendem Nebel und Wolken auffangen, Meteor. Zeitschr. 23, 547-553.

The study stresses the influence of the leaves of the trees on the deposition of water from the fog droplets. Some results of observations are quoted.

4.1

Mason, B. J. 1957

The Physics of Clouds, Carendon Press, Oxford.

The author deals mainly with microphysics of clouds and precipitation. The book includes an introductory chapter on cloud dynamics by Ludlam and chapters on radar meteorology and atmospheric electricity related to the cloud and precipitation formation. It presents a complete theory of nucleation, droplet and ice crystal growth and contains very useful reference list.

1.2 - 1.3 - 1.6 - 1.7 - 6.1

Mascart, Jr. 1938

Une nouvelle theorie du brouillard, Lyon, Bull, obs., 9, 74-75.

2.1 - 2.2

Mason, B. J. 1975

Clouds, Rain, and Rainmaking, 2nd Edition, Cambridge Univ. Press, Cambridge, pp. 189.

pp. 132-133 contain a description of the seeding of layer clouds during the project cirrus with dry ice at the temperature between -3.5°C and -5°C (above the top of clouds). Other experiments with dry ice over Maine at the temperature lower than -5°C are described during which 1 to 10 lb. per mile were dispersed and a cloud of 500 ft. in depth was made transparent during 10 minutes.

6.1

McAdie, A. 1934

Fog, New York, Macmillan Co., 23 pp., pls 53.

2.1 - 2.7

McCabe, L. C. 1952

United States Technical Conference on Air Pollution, Washington, 1950, Air Pollution Proceedings, McGraw-Hill. New York

1.1 to 1.11

McCormack, J. D. and R. K. Hilliard 1970

Scavenging of Aerosol Particles by Sprays, in Precipitation Scavenging (1970), U.S. AEC, Oak Ridge, Tenn. December, 187-204.

The washout of aerosol particles in a closed chamber of 750 m^3 volume was checked. Water soluble cesium, iodine particles and uranium oxide particles in the size range between 0.3 to 2.0 μm were used and collection efficiencies established.

5.9

McCully, C. R., M. Fisher, G. Langer, J. Rosinski, H. Glaess, and D. Werle 1956

Scavenging Action of Rain on Air-borne Particulate Matter, Ind. Engin. Chem. 48: 1512-1516.

Description of a scavenging experiment is presented: Aerosol particles of known size spectrum distribution are blown against a fixed drop as a collector and observed or photographed the portion which is rebounding or collecting. The general parameters influencing the catching energy of nonwettable particles and the interfacial tension are put into relation. Laboratory facility for dust washout is described together with the experiment in the atmosphere. The final conclusion is that the rain washes in mean 35-50% each day of all dust particles in the atmosphere.

4.1

McDonald, G. et al 1964

Scientific Problems of Weather Modification Nat. Academy of Sci., Nat. Res. Council, Public. No. 1236, Washington, D. C., 60 pp.

For cloud seeding Weickmann suggested HCl SO_3 (mixture) which is capable to produce 6.10^{13} nuclei per g of mixture. This process supports further the coalescence. The warm fog seeding techniques are limited to the dispersion of the black fumes and to those de Magono. Supercooled fog seeding uses mostly dry ice and silver iodide.

4.3 - 5.6 - 5.12 - 6.1

McDonald, J. A. 1960

Le FIDO sur les aéroports civils, Shell Aviation News, 257, 17-19.

The study summarizes the experiences made with FIDO at the airport at London. Some of the necessary requirements for a successful operation are mentioned.

5.1 - 6.1

McDonald, J. E. 1963

The Saturation Adjustment in Numerical Modeling of Fog, J. Meteor. 20, 476-489.

2.2 - 2.5

McDuff, J. M., Z. J. Moore, and L. Chambley 1973

Warm Fog Dispersal Tests with Glycerine in the Panama Canal Zone, Part I, Washington FAA, Syst. Res. Dev. Serv. Rep. No. FAA-RD-73-21, Part I, pp. 33.

4.3 - 6.1

McDuff, J. M., Z. J. Moore, and J. W. Goode 1973

Warm Fog Dispersal Tests with Glycerine at Greenbrier Valley Airport, Lewisburg, West Virginia, Washington FAA, Syst. Res. Dev. Serv. Rep. No. FAA-RD-74-1, Final Rep. Phase II, 4°, pp. 55.

4.3 - 6.1

Mednikov, E. P. 1965

Acoustic Coagulation and Precipitation of Aerosols, (transl. from Russian by Chas. V. Larrick), Consultants Bureau Enterprises, Inc., New York, 180 pp.

The author deals with aerosol physics and its application for dust and drop collecting technology in acoustic fields. Theoretical models are compared with the measurements under specific conditions in the laboratory.

4.5

Melkaia, I. Ju. 1968

Statsionarnaia model radiatsionnogo tumana, Izv. AN SSSR, Fizika Atmos. i Okeana, 4, 220-223.

Under simplifying assumptions a model of radiation fog is deduced and on some numerical examples is shown its usefulness.

2.1 to 2.5

Mészáros, E. 1968

A felhőfizika tanulmányozása a jégesők, alacsony felhőzet és a ködök befolyásolása céljából, Hivatalos Kiadványai, Vol. 33, 1967, Országos Meteor. Intézet, Hungary, Oct. 224-231.

(Studies in cloud physics undertaken in view of artificially influencing hail, low clouds and fogs.)

General survey on the possibility of weather modification based on some measurements of the chemical composition of the atmosphere is made.

6.1

Miller, H. G. et al 1974

Trockeneis löst Nebel auf, Die Umschau, 74, 616-617

A description of the physical processes including the experiments in nature is attached. Positive results in clearing of supercooled fog were obtained on the surface of 10 miles² (30 min - of duration).

5.12 - 6.1

Monin, A. S. 1959

Smoke Propagation in the Surface Layer of the Atmosphere, Atmospheric Diffusion and Air Pollution, Ed. by F. N. Frenkiel and P. A. Sheppard, Adv. Geophys. 6, 331-343 (Academic Press).

2.5 - 3.1 - 3.2 - 3.3

Miller, H. G. et al 1974

Versuche zur Beseitigung unterkühlten Nebels in Oberpfaffenhofen. Ann. Meteor. Neue Folge, Offenbach, 9, 61-64.

6.1

Monin, A. S. and A. M. Yaglom 1973 1975

Fluid Mechanics, The MIT Press, Cambridge, Mass., Vol. I (1973), 769 pp., Vol. II (1975), 874 pp.

Vol. I contains the basic descriptions of laminar and turbulent flow, of turbulence in stratified medium, and particle dispersion in turbulent flow (turbulent diffusion) Vol. II. concentrates on the mathematical description of turbulence, correlation and spectral functions, spectral energy - transfer hypothesis, locally isotropic turbulence and wave propagation through turbulence.

2.6

Montefinale, A. C. et al 1970

Preliminary Tests on Large-Scale Suppression of Warm Fog by Means of Giant Monodisperse Particulates. Part I. The first Ghedi-Monte Orfano Experiment. Part II. One Extensive Systematic Experiment in the Ghedi-Monte Orfano Area, Pure Appl. Geoph., Basle, 83, 167-172, p. 173-181, 2 & 8 ref.

4.3 - 5.6

Monteith, J. L. 1972

Survey of Instruments for Micrometerology, Blackwell Sci. Public, Oxford

A useful survey about instrumentation used for the measurement of meteorological parameters in the atmospheric boundary layer. Technical parameters on thermometers, psychrometers, dew-point meters, anemometers, pyrheliometers, pyranometers and actinographs from all parts of the world are presented with the addresses of the producers.

2.1 - 2.2 - 2.3 - 2.4

Morachevskii, V. G., and B. M. Shinimev 1968

Study of Fog Properties in a Cloud Chamber, Canada, Meteor. Branch, Met. Translat. No. 15: 1-3.

The use of cloud chambers for the studies of fog dispersal using surface-active nuclei, (powders of allylbenzosulfonates).

4.3

Muller, M. G. 1960

Expériences d' ensemencement de brouillard surfondu avec l' iodure d' argent. Beitr.z. Physik d. Atmos. 33, 1-8.

The experiments were performed with a generator of agI placed on the ground. The photographs of holes were presented.

5.12

Natanson, G. L. 1960

On the Theory of the Charging of Amicroscopic Aerosol Particles as a result of Capture of Gas Ions, Sov. Phys. Tech. Phys. 5: 538-551.

Theory is established for the capture of ions on particles with dimensions much smaller than the free path of molecules ($\ell = 10^{-5}$cm).

1.6

National Science Foundation 1969

Weather Modification, 10 th report 1968, 141 pp.

The Chapter IV deals with the dispersion of fogs. The experiments in the USA 1968 at Fort Rucker (Alabama) showed that the most efficient methods are as follows: 1) dissipation by the emission of heat, 2) dissipation by the downdraft below a helicopter, 3) the dissipation by the use of hygroscopic nuclei. It is necessary to know more about the macrostructure of a fog.

5.1 - 5.5 - 5.6

National Science Foundation 1966

Weather Modification, 8th Report, 132 p.

Fog dispersion was successful in the case of supercooled fogs, (CO_2, AgI), however, unsuccessful in the case of warm fogs.

6.1

Neiburger, M. 1969

Artificial Modification of Clouds and Precipitation, WMO, Tech. Note, No. 105, 33 p.

The author analyses all main fields of weather modification. The chapter IV contains the notes on the dispersion of the supercooled fogs (Serpolay, 1965), and through enhancement of the collision of the droplets.

5.12 - 6.1

Nikandrov, V. J. 1958

The Problem of the Artificial Control of Cloud and Fog, Gidrometeoizdat, Leningrad, 13, pp. 1, 19 ref.

A note on the possibility of controling the origin and development of cloud and precipitation. Dissipation of fog is included. Quotations mainly of the Russian authors.

6.1

Nikandrov, V. Ja. 1962

Dry Torches as a Means of Introducing Crystalline Nuclei into Fog from the Ground. (In Russian) Trudy GGO, Leningrad, Vyp. 126, 22-24.

5.12 - 6.1

Nikandrov, V. Ja. 1959

Artificial Modification of Cloud and Fog (Microphysical Basis), Leningrad (Gidrometeoizdat), 1959, 8 Vo., 191 pp.

6.1

Nikandrov, V. Ja. 1967

Aktivnye vozdeistvia na oblaka i tumany, Trudy GGO, Leningrad, 218, 251-260.

The survey is presented about the Russian activity on the f eld of cloud and fog modification and rain stimulation. Also the hail prevention program is outlined in detail. The article pays attention to the historical development of weather modification in Russia and contains many references up to 1965.

6.1

Nolan, J. J. 1926

The Breaking of Water-Drops by Electric Fields, Proc. Roy. Irish Acad. Vol. 37, A, No. 3, 1.

The desintegration of the drops in the electrical field is proportional to the

$\sqrt{\frac{\sigma}{r}}$ σ = surface tension
r = radius of drop

The larger drops contribute to the neutralization of the existing electrical field.

1.6 - 4.4

Nordstrom, R. J., R. K. Long and E. K. Damon 1977

A Synergistic Investigation of the Infrared Water Vapor Continuum. "Unsolocited Proposal to Army Research Office, Durham, North Carolina from Ohio State Univ. Electroscience Laboratory, Department of Electrical Engineering, Columbus, Ohio 43212.

A research proposal to investigate the continuum water vapor absorption in the 8 to 12 μ and 3.5 μ to 4 μ atmospheric windows. A copy of this document (obtained from R. J. Nordstrom) provides an excellent review and bibliography of the work previous to Feb. 1977 on the controversial "continuum" absorption in the Infrared windows. (The proposal was funded.)

1.5 - 4.6

Olivier, J. 1956

Essais d' atténuation artificielle du brouillard, Bull. C.N.R.S. Obs. Puy de Dome, 1, 4-6.

The description is made of an experiment at the airport of Lyon-Bron with the propane technique (Serpolay); after the third seeding at -4°C the visibility improved.

5.12

O'Neill, T. H. R. 1968

Current and Future Weather Modification Programs of the Department of Defense (in Taubenfeld H. J.: Weather modification and the law, Dobbs Ferry, N. Y., Oceana Publications, Inc. p. 31-43).

Three major areas are covered: Cold fog and clouds, warm fog and clouds, convective cloud systems: Among the techniques are described in detail: propane gas, supercooled fog modification, AWS Project Cold Fog II, contrail suppression. In the domain of warm fog; USAF project "Catfeet" and others are mentioned.

6.1

Osmun, W. G. 1969

Airline Warm Fog Dispersal Program, Weatherwise, Boston, 22: 48-53.

Fog seedings experiments from aircraft and from the ground as well were performed in Sacramento, Los Angeles and at Nantucket. The efficiency of hygroscopic particles was proven in warm and cold fog (NaCl). "Polyelectrolytes and surfactants are more effective and seeding was not as precisely conducted as in operations which disperse salt."

4.3 - 6.1

Pasquill, F. 196?

Atmospheric Diffusion, Van Nostrand, New York,

A standard textbook on the diffusional phenomena in the atmospheric boundary layer. Contains the discussion of the stability of the atmosphere, turbulence and its influence on momentum, energy and mass transfer. An extended survey of the literature mainly of western countries is attached.

2.5 - 2.6

Oura, H. and J. Hori 1953

Studies in Fogs, Hokkaido Univ.

The report presents a complex study of the physical conditions of marine fog microstructure and the means of clearing the fog or increasing the visibility. A careful study of micrometeorological conditions shows that a possible solution is to plant a belt of trees along the highways in order to catch the droplets on their leaves.

2.6 - 5.9

Pasquill, F. 1962

Atmospheric Diffusion; the dispersion of windborne material from industrial and other sources. Princeton, London, Van Nostrand, 297 pp.

he author covers a broad field of atmospheric diffusion mainly in the boundary layer. The conditions of air stability and turbulence are analyzed in detail and their influence on dispersion of pollutants is investigated.

3.1 - 3.2 - 3.4

Pasquill, F. 1971

Atmospheric Dispersion of Pollution, Quart. J. Roy. Meteor. Soc., 97: 369-395.

"Meteorologists are now finding their rather traditional interests in the way the atmosphere moves and dilutes windborne material... Except on the local scale, however, these are issues on which much scientific advance needs to be made before anything more than dubious speculations become possible." A critical discussion of the gradient, statistical and similarity theory with the distribution from multiple sources.

2.5 - 3.1 - 3.2 - 3.3

Parker, W. J. 1969

Polarographic Analogues for Disper. Nature, London, 222: 655.

The displacement of fog is suggested to be reached by creating a stable disperse phase diffusion layer at the interface between the fog base and a thin layer of dry air at lower temperature injected on to the runway. The dry air is produced by the evaporation of liquid air through heated directional louvers on either side of the runway. It can displace the fog to a height of 40m and 100m wide. Precipitation of the fog by exposure to a large area of surface cooled to a very low temperature by liquid air is proposed.

5.5 - 5.10

Parker, L. W. 1974

Diffusive Collection of Small Particles by Charged Raindrops, Pres. Scavenging Sympos. Champaign, Ill., Oct. 14-18, 39 pp.

1.6 - 4.4 - 5.8 - 5.9

Partl, W. 1961

Anregung zu einim Versuch zur Beseitigung von Strahlungsnebel durch Hubschrauber, Wahn - Heide, Bundeswehr allgem. Luftwaffe, Abtl. Wetter, Fachl. Mitteilungen 1, No. 50, 10 pp.

5.4 - 5.5

Pasquill, F. 1974

Dispersion of pollutants by atmospheric turbulence, in Turbulent Diffusion in Environmental Pollution, Adv. in Geophys., Academic Press, New York, 1-13.

A survey of the achievements of the three methods (gradient-transfer concept, statistical theory, dimensional analysis) in describing dispersion of pollutants in the atmosphere. A comparison with some measurements is attached.

2.5 - 2.6 - 3.1 - 3.2

Patterson, H. S. and W. Cawood 1936

The determination of the distribution is smokes. Trans. Faraday Soc. 32, pp. 1084-1888

Discussed are: 1) photometric method, 2) graticule method. Limitations of the photometric method are mentioned. Graticule method is suitable for particles within size ranges of 0.1 to 2.5 µm.

1.2

Patterson, A. M., and C. J. West 1918

War Gas Investigations, Bureau of Mines Monograph No. 7, England

1.3

Paugam, J.-Y., and R. Serpolay 1970

Modification de la densité optique des brouillards par ensemencement d' alginate pulverulent. Comparison avec les ensemencements de NaCl. J. Rech. Atmos., 4, 101-106.

T e water absorption by the noncorrosive sodium alginate powder was checked and compared with that of NaCl. The :esults support the idea that the effect of both substances might be comparable if the amount of sodium alginate would be about six times larger than these used for NaCl seeding (i.g., 2, 13 g NaCl compared to 11, 07 g of alginate).

4.3 - 5.6

Panthenier, M. and R. Cochet 1953

Évolution d' une gouttelette d' eau chargée dans un nuage a température positive, Revue Gen. de l' Electr., 62, 255-262.

The numerical calculation of a charged droplet growing in an atmosphere humid due to the condensation. Small droplets highly charged can grow very fast.

4.4

Peters, E. 1957

Eine neue Methode zur Bestimmung des Gehaltes an flüssigem Wasser in Wolken und Nebeln nach F. Albrecht, Zeitschr. f. Meteor. 11, 118-124.

A detailed description of the method of the liquid water content is based on the heating of the cylinder on which the fog drops are impacting. The temperature change of the rod due to the evaporation of droplets is proportional to the liquid water content of the fog.

4.1

Pena, J. A. 1968

Nombre de particules de glace formées par nucleation hetérogène dans le brouillard d' une analyseur de pouvoir glacogène, J. Rech. Atmos. 3, 229-243.

Behavior of a supercooled fog in a mixing chamber was studied. Heterogeneous nucleation process is briefly analyzed. The calculated concentration of freezing nuclei is of the same order as that of the ice nuclei.

5.12

Perrin de Brichambaut, C. 1968

Modification artificielle du temps et du climat. Possibilités d' interventions humaines, La Météorologie, 5, 15-57.

A survey about different techniques is rather pessimistic. The author states that the most successful was the dispersion of fogs at temperatures lower than 0°C by the dry ice. Further the author suggests that $CaCl_2$ might be more efficient than NaCl.

4.3 - 5.1 - 5.12 - 6.1

Pepper, D. W. and S. C. Lee 1974

Transport Phenomena in Thermally Stratified Boundary Layers, Proc. AIAA/ASME Thermophysics and Heat Transfer Conf., July 15-17, Boston.

2.5 - 2.6

Petterssen, S. 1941

Recent fog investigations, J. R. Aeron. Soc. 45: 77-88, J. Aeron. Sci., 8, (1941), 91-103.

2.1 - 2.2 - 2.4 - 2.5 - 2.7

Petterssen, S. 1939

Some aspects of formation and dissipation of fog., Oslo, Geopys. Publ, 12, No. 10: 22p.

2.1 - 2.2 - 2.4 - 2.5 - 2.7

Pham - Cong, L. *1969*

Influence du champ et des charges électriques sur la précipitation du brouillard. Thèse du Doctorat-ès-Sciences, Université Laval.

1.6 - 4.4

Pham - Cong, L., and J. B. Jordan 1969

Fog Droplets in Electrostatic Field, IEEE trans. on Geoscience, Electronics, GE-7, 258.

1.6 - 4.4

Pilie, R. J. 1969

Review of Project Fog Drops, U. S. NASA, Spec. Public. SP-212, 1-23.

Program of the Project Fog Drops-Warm Fogs: Study of concentrations of fog and haze nuclei, descriptive models, inhibition of droplet growth, investigation of effects of ions surfactants on coalescence, investigation of electrical means for fog dispersal, method for prevention of dense radiation fog are discussed.

4.3 - 4.4 - 4.8

Picca, R., H. Gase, and R. Mailhes 1968

La production de cristaux de glace dans une chambre a détente, J. Rech. Atmos. 3, 345-352.

Natural air and air polluted with AgI particles are investigated during an expansion process in a chamber. The results are compared with a similar experiment in a mixing chamber.

5.12

Pilié, R. J. 1969

Verification in Laboratory Seeding Experiments, U. S. NASA, Spec. Public. SP-212, 40-56.

Checking of the Jiusto's experiments using NaCl particles: 4 to 7 times improvement of visibility was found using 1,6 mg NaCl m^{-3} at diameters of 4 µm but no effect at 0,8 mg m^{-3} was observed.

4.3 - 5.6

Pilié, R. J., J. E. Jiusto, W. C. Kocmond and W. J. Eadie 1969

Progress of NASA Research on warm fog properties and modification concept. Presented during a symposium held at NASA Headquarters NASA SP-212, 122 pages.

6.1

Pilié, R. J., W. C. Kocmond, and J. E. Jiusto 1967

Warm Fog Suppression in Large-Scale Laboratory Experiments, Amer. Assoc. Adv. Sci., Washington, 157, 1319-1320, 2 ref.

4.3 - 5.6

Pitter, R. L., and H. R. Pruppacher 1974

A Numerical Investigation of Collision Efficiences of Simple Ice Plate Colliding with Supercooled Water Drops, J. Atmos. Sci. 31, 551-559.

The authors investigate the collision efficiency of an oblate ellipsoid with spherical drops. They deduced a critical ice crystal size (oblate ellipsoid diameter) below which the plate type crystal will not collect any drops of a given size. Comparison with some observations are made.

4.1 - 5.9

Plank, V. G. 1969

Clearing Ground Fog with Helicopters, Weatherwise, Boston, 22: 91-98.

The efficiency of fog dispersion using the helicopter rotor wind is proved on several examples.

4.7 - 5.4 - 5.5 - 6.1

Plank, V. G. and A. A. Spatola 1969

Cloud Modification by Helicopter Wakes, J. Appl. Meteor. 8, 566-578.

The authors analyzed the effect of clearing clouds and fog under the helicopter due to the air mixing and due to the warming of the air by the engine exhaust. The downwash field is not stable and is divided into three zones in which the velocities are expressed in empirical formulas.

5.4 - 5.5

Plumlee, H. and R. Semonin 1965

Cloud Droplets Collision Efficiency in Electric Fields, Tellus, 17, 356-

1.6 - 4.4

Plaude, N. O., and A. D. Soloviev 1965

On the Use of Particles with Large Specific Surface Area for Seeding Clouds and Fogs, Moscow, Trudy CAO, pp. 65, 30-47, 16 ref.

The authors discuss the properties of substances with large specific surface area and their application for potential seeding of warm clouds and fogs.

4.3

Pochettino, A. 1938

La dissipazione della nebbia, Scientia, 63: 191-199.

6.1

Podzimek, J. 1959

Fysika oblaku a srážek (Cloud and Precipitation Physics) Nakl. CSAV, Praha, 486 pp.

The book (in Czech) deals with the water phase transition in the atmosphere, the origin of clouds and precipitation. A special chapter is dedicated to condensation nuclei and their role in cloud formation. The microstructure of water, mixed and ice clouds is discussed in connection with the formation of precipitation. A brief survey of the problems related to the properties of precipitation elements and to the artificial interference into cloud and precipitation formation is attached.

1.2 - 1.3 - 1.4 - 1.7 - 2.1 - 2.2 - 6.1

Podzimek, J. 1961

Über die Bindung de Aerosolteilchen auf der Oberfläche der Wolkenelemente, Geofis. Pura e Applic. 50: 161-168.

The simplified diffusion equation is used for the calculation of the catching of aerosol particles on the surface of drops on which water vapor condenses. A numerical example shows the possible importance of this process for the scavenging of aerosol in comparison with the Brownian and turbulent movement.

5.1 - 5.9

Podzimek, J. 1965

L' influence du courant de Stefan sur la capture des particules d' AgI sur les elements de nuage, J. Rech. Atmos., 19-26.

The application of the electrostatic analogy for the solution of catching of the AgI particles on cloud elements is outlined. Special attention is paid to the catching of aerosols on the surface of ice crystals.

4.1 - 5.9

Podzimek, J. 1966

A Contribution to the Question of Binding of Aerosol Particles on Cloud Elements, J. de Rech. Atmosph. 1: 309-314.

The general Kolmogoroff equation is used to explain the character of the catching of aerosol particles under the influence of thermophoresis, diffusiophoresis and Stefan flow.

4.1 - 5.9

Podzimek, J. 1966

A contribution to the question of binding of aerosol particles on cloud elements, J. Res. Atmos. 2, 309.

The author investigates the catching of tiny aerosol particles on the surface of cloud elements. Rough calculation shows that Stefan flow mechanism might be effective in scavenging aerosols mainly in mixed clouds.

4.1 - 5.9

Podzimek, J., and A. N. Saad 1974

Evolution of Giant Chloride Nuclei Size Spectrum on the Seashore, Arch. Met. Geoph. Biobl. Ser. A, 23, 77-86.

The application of Junge's and Nukiyama-Tanasawa size distribution to the sea salt nuclei size distribution is discussed. From the nuclei activity term supersaturation-size spectrum for both functions is deduced.

1.2 - 1.7

Podzimek, J. 1967

Rost ledianogo kristalla v smeschannom oblake, Sympos. on Cloud Physics, Bul. Academy of Sci., Geophys. Inst. Sofia, November, 161-172.

The author deals with the modeling of an ice crystal growth in a mixed cloud. Simple relations between the ice crystal growth by condensation and coagulation and its environment are established. Different types of ice crystal motion in the atmosphere are simulated in a tank filled with glycerol and formulas for settling of differently shaped crystals established.

4.1 - 5.9

Polovina, I. P. 1968

O rezul'tatakh rabot po rasseianiiu pereokhlazhdennykh oblakov i tumanov i vozhmostiakh provedeniia ikh nad aeroportami Ukrainy, Trudy Nauchno - Issled. Gridromet. Instituta, Kiev, No. 74:32-43.

On the basis of 11 years of observations at 9 stations in the Ukraine data on the duration of supercooled fogs and low clouds were obtained. 50 - 60% of fogs at velocities < 2m/s are suitable for seeding in the winter time.

5.12 - 6.1

Presle, G. and H. Horvath 1978

The Influence of the Color of Visibility Targets on the Visibility. Pageoph (in print), 16 typewritten pages.

Observation of colored targets in hydrosols produced the following results: For atmospheric aerosols with visual detection one must use the wavelength at maximum perception to calculate visibility. It is suggested in the atmosphere that 5800A rather than 5500A be used in this type of calculation. Observed visibilities agreed with calculated ones if the visibility was calculated from the intrinsic brightness of the objects and the extinction coefficient was used to calculate the wavelength of miximum perception before the visibility is contemplated.

1.5 - 4.6

Presle, G., and H. Horvath 1978

The Visibility in Turbid Media with Colored Illumination. Accepted for publication in Atmospheric Environment (15 typewritten pages).

Observations of targets in a hydrosol were made through colored filters. The hydrosols had wavelength dependent extinction coefficients(A) similar to the atmosphere and(B) with a higher extinction in the red. The results indicate that one must use the wavelength at visual (eye) maximum perception rather than the dominant wavelength of the filters in visibility calculations using air extinction coefficient. For daylight and normal aerosol the wavelength found most useful is 5800. Calculations of wavelength of maximum operation for several extinction coefficients are presented.

1.5 - 4.6

Prichotko, G. F., L. M. Roev, and M. V. Tovbin 1964

On the Question of Using Monomolecular Films for the Prevention of the Sea Smoke Type of Fog. (In Russian) Leningrad, Meteor. i Gidrol., 11, 27-29.

4.3

Pristley, C. H. B. 1959

Turbulent Transfer in the Lower Atmosphere, Univ. of Chicago Press, Chicago, Ill.

A monograph on the turbulence and turbulent exhange in the atmospheric boundary layer. An extended survey of the published articles, reports and books mainly in western countries is attached.

2.5 - 2.6 - 3.1 - 3.2

Prokhorov, P. S., and L. F. Leonov 1961

Issledovanie diffuzionnykh sil dalnodeistvia nezhdu vodiannymi kapliami i neletuschimi chastitsami, Koll. Zhurn. 13, 464-467.

Description of an experimental proof of the validity of the theory of diffusiophoresis using a fine balance (sensitivity 0.4×10^{-8}g) is presented. At the drop radius $r = 1$ um and a humidity 55-60% the repulsing force was 1.6 10^{-8}dynes what is 2-2.5 more than the theory predicts. (The investigation of the diffusion forces acting on a distance between water drops and insoluble particles.)

4.1 - 5.9

Rabbe, A. 1969

Cold Fog Seeding at Oslo Airport, Fornebu, During Winters 1967-68 and 1968-69, Meteor. Annaler, *Vol.* 5, *No. 9, Norske* Meteor. Institutt, Oslo, 363-393.

5.12

Rabbe, A., S. Hoppestad, *and* R. Eriksen 1968

Cold Fog Occurrence at Oslo Airport and Methods of Artificial Dissolution, Meteorologiske Annaler, Oslo, 5: 31-43.

It is assumed that there are 6 periods lasting more than 5 hours in the winter time during which should be fog seeded. The scientists prefer dry ice seeding for physical reasons and propane seeding for economical reasons.

5.12 - 6.1

Rayleigh, Lord 1879

On the *Equilibrium of Liquid Conducting Masses Charged with Electricity*. Proc. Roy. Soc., 184-186.

1.6 - 4.4

Rebenstorff, H. 1904

Ein einfacher Apparat zur Untersuchung der Nebelbildung und uber Anordnung der Nebelkerne bei der elektrischen Spitzenentladung, Physik, Z., 5, 571-574.

1.6 - 4.4 - 5.8

Reinking, R. G. et al. 1977

Project Foggy Cloud VI: Design and Evaluation of Warm-Fog Dispersal Techniques, China Lake, War Weap. Contr. Tech. Publ. 5824, pp. 106, 23 ref.

4.4 - 5.8

Reiter, R. 1974, 1975

Boundary Layer Aerosol Transport Measurements in a Valley System. Part I., Final Tech. Rep. 1974, Contract No. DAJA-37-73-C-1806, 16pp. Part I., Final Tech. Rep., June 1975, Grant No. DA-ERO-124-74-60054, 29pp.

1.10 - 1.11 - 2.5

Reiter, R. and W. Carnuth 1975

Remote Aerosol Sensing with an Absolute Calibrated Double Frequency Lidar. 22nd Tech. Meeting of AGARD on Optical Propagation in the Atmosphere, Lyngby, Denmark, October.

1.11

Richardson, L. F. 1920 a

The supply of energy from and to atmospheric eddies, Proc. Roy. Soc. Ser. A, 97, 354.

The author studies the damping of small perturbations of a shear flow having a mean velocity $\bar{u}(z)$. The damping depends on the value of the nondimensional parameter

$$Ri(z) = \frac{g}{T(z)} \frac{\Gamma_0 - \Gamma(z)}{(\partial \bar{u}/\partial z)^2} .$$

The perturbations are damped if $Ri > Ri_0 = 1.0$.

2.5

Rinehart, G. S. 1969

Fog drop size distributions: measurements methods and evaluation, U. S. Army Electronics Command, Ft. Monmouth, N. J. ECOM5247, April 39.

Critics of the methods using gelatine, formvar and polyvinyl alcohol, and oil collection media for recording droplets less than 4μ diam. is presented. The secondary influence of certain pyrotechnical mixtures on the generation of tiny fog droplets which can play an important role in visibility studies is stressed.

1.1 - 1.2 - 4.1

Richardson, L. F. 1920 b

Some measurements of atmospheric turbulence, Phil. Trans. Roy. Soc. London, Ser. A, 221, 48.

The author presents results of the extensive series of experiments with turbulent diffusion using chimney smoke, and chemical smokes such as NH_4Cl, P_2O_5 etc. The smallest value of turbulent viscosity coefficient was 78 $cm^2\ sec^{-1}$ at 30 cm above the lawn in still air, and the largest 1.6×10^6 $cm^2\ sec^{-1}$ at 250 m.

2.5 - 2.6 - 3.1

Roach, W. T., R. J. Adams, J. A. Garland, and P. Goldsmith 1973

A Field Study of Radiation Fog, Faraday Symp. of the Chem. Soc., 7: 209-221.

A detailed analysis of the origin and transformation of a radiation fog is presented. Some of the conclusions of a one-dimensional model including the heat, water vapor and liquid water budget are confronted with the parameters measured inside a typical radiation fog of 7 December, 1971 at Cardington, Beds.

2.1 to 2.7

Rogers, C. W., E. J. Mack, and R. J. Pilié 1972

Experimental Test of Fog Clearing by Ground-Based Heating-Visibility, Temperature, and Fog Microphysics, AFCRL-TR-73-0056, Buffalo, N.Y. Calspan, Contract No. F19628-72-C-0160, Sci. Rep. No. 1, pp. 57.

5.1 - 5.5

Rogers, C. W., W. J. Eadie, U. Katz, and W. C. Kocmond 1975

Project Fog Drops V., NASA, CR-2633, Washington, D. C., December, 76pp.

A two dimensional model has been used to describe the on-setting and evolution of an advection fog. The main equations include the time change of potential temperature, water vapor mixing ratio, wind components u and v. The model also includes the influence of radiation on the fog evolution.. No microstructural calculations were made.

2.1 - 2.2 - 2.4 - 2.5

Rosinski, J., and T. C. Kerrigan 1979

Formation of Ice Phase by Contact Freezing, Sorption, and Condensation-freezing in Natural and Seeded Storms, J. Rech. Atmos., 11, 77-97.

The article deals with a simplified theory of the deposition of particles seeding the supercooled water drops due to the Brownian diffusion theory modified by thermo- and diffusiophoresis.

5.12

Rosinski, J., R. H. Snow, and F. B. Smith 1958

Models for Computing Contamination Expected from Aircraft Spray, CWL Spec. Publ. #2, Rep. on Symposium VIII, Vol. I, U. S. Army Chem. Warfare Lab., July.

The authors present a simple model for particle dispersion in the atmosphere. The models bear in mind the particle settling and assume a particle size distribution close to the Nukiyama-Tanassawa distribution.

3.1

Rossby, C. G. and R. B. Montgomery 1935

The Layer of Frictional Influence in Wind and Ocean Currents, Pap. Phys. Ocean. Meteor., MIT, Woods Hole Ocean. Insti., Vol. 3, No. 3, 101 pp.

2.3 - 2.5

Rouleau, M. and M.-M. Poc 1967

Electrocongelation des brouillards surfondus, C.R. Acad. Sci. 224, Ser. A and B, No. 21.

The authors succeeded to transform the fog (supercooled) by the means of the use of an electric field of high intensity which caused the freezing of supercooled water droplets.

5.8

Roth, L. O., and J. G. Porterfield 1970

Spray drop size control, Amer. Soc. Agri. Eng., Trans. 13, 779-789

1.2 - 1.3

Runge, H. 1937

Entstehung von Bodennebel durch Auspuffgase, Z. angew. Met., 54, 307-308.

4.3 - 5.6

Saad, A. N., J. Podzimek and J. C. Carstens 1976

Some Remarks on Modeling of the Early Stage of Cloud Formation in a Simulation Chamber, J. Appl. Met., 15, 145-156.

The authors use a numerical model to describe the early stage of droplet formation in a small simulation chamber. The updraft (pressure) and temperature fluctuation are considered together with the possible effect of cloud seeding or by hygroscopic nuclei or by surfactants.

4.3 - 5.6

Saffman, P. G. and J. S. Turner 1956

On the collision of drops in turbulent clouds, J. Fluid Mech. 1, 16-30.

4.1 - 5.9

Sachsee, H. 1932

Über die elektrischen Eigenschaften von Staub und Nebel Ann. der Physik, Leipzig, 14, 396-412.

1.6 - 4.4

Sakagami, J. 1956

On the Atmospheric Diffusion of Gas or Aerosol Near the Ground, Natural Science Report, Ochanomizu Univ. 7, 25-61

Aerosol or gas from different points in the space is released. Line type source and source within five meters from the ground is considered. The importance of similar calculations for agriculture, meteorology and industry is stressed.

3.1 - 3.2

Sample, S. B. and R. Bollins 1972

Production of Liquid Aerosols by Harmonic Electrical Spraying. J. Coll. Sci., 41, 185-193.

1.6 - 4.4

Sanders, P. A. 1970

Principles of Aerosol Technology, Van Nostrand Reinhold, New York, pp. 418

1.1 to 1.11

Sartor, J. D. and Ch. E. Abbott 1968

Charge Transfer Between Uncharged Water Drops in Free Fall in an Electric Field. J. Geophys. Res. 73, 6415-6423.

1.6 - 4.4

Sartor, J. D. and C. E. Abbott 1972

Some Details of Coalescence and Charge Transfer Between Freely Falling Drops in Different Electrical Environments J. Rech. Atmos. 6, 479-493.

The authors did investigate the coalescence of charged droplets falling in an electric field. They concluded that the electrical environment has a measureable effect on the coalescence efficiency of colliding water drops. The efficiency depends on size and size ratio of drops, their charge, the electrical environment, and the relative velocity of their encounter. The drops were usually between 0.25 to 0.40 µm in size.

1.6 - 4.4

Sasyo, Y. 1971

Study of the formation of Precipitation by the Aggregation of Snow Particles and the Accretion of Cloud Droplets on Snowflakes, Papers in Meteor. and Geophys. 22, 69-142.

A very detailed investigation of the collection efficiency of ice crystals in a water cloud. The author formulates a simple mathematical model and makes experiments in an aerodynamic wind tunnel with models of plate type ice crystals.

4.1 - 5.9

Schafer, V. J. 1968

What about the next twenty years? Weatherwise Boston 21: 114-117.

Review of seeding experiments including Yellowstone expedition 1968. General problems related to air pollution are mentioned.

5.12

Sawyer, K. F. 1942

The Effect of Relative Humidity upon Screening Power of F. M. Smoke, Porton Rep. No. 2448, (Sec. No. 71), Nov.

Performance in the field will depend on the extent of coagulation permitted by the conditions in which the smoke is put up, and on occasions it may not be possible to achieve more than about half the performance obtained in the laboratory. F. M. produces no smoke in dry air, but produces a dense, stable smoke of the hydrate (presumably $TiCl_4 \cdot 5H_2O$) when only a small amount of moisture is present.

1.7

Schmeter, S. M. 1972

Fizika konvektivnykh oblakov, Gidrometeoizdat, Leningrad, 232 pp.

The monograph deals with the description of the origin and growth of a convection cloud. Special chapters deal with atmospheric stability, air entrainment. The author describes the results of the measurements of cloud microstructure and the attempts to model numerically convective clouds.

2.5 - 2.6

Schweizer, J. W. and D. N. Hanson 1971

Stability Limit of Charged Drops. J. Coll. Interf. Sci. 35, 417-423.

1.6 - 4.4

Scientific Problems of Weather Modification 1964
(A Report of the Panel on Weather and Climate Modification Committee on Atmospheric Sciences), Nat. Academy of Sciences; Nat. Research Council, Washington.

The report deals with all possible aspects of weather modification including the modification of supercooled clouds and fogs and dispersion of warm clouds. The first topics are considered to be the most prospective. Several methods of warm cloud seeding were applied; Carbon black seeding (radiational transfer-Vonnegut); 40 kg carbon powder per km^2 at noon time; heating of the air and seeding of fog with water (*Magono*).

6.1

Scorer, R. S. 1968 (1972)

Air Pollution, Pergamon Press, Oxford, 1972, 151 pp.

The booklet on problems related to air pollution, its physical basis, economical and health aspects is written for non-professionals, however, on a strict mathematical-physical basis. The equations and theoretical statements are presented without any proof or detailed explanations. The content covers the description of pollution over different kind of terrain, influence of meteorological factors and damages caused by air pollution.

2.5 - 2.6 - 3.1 - 3.2 - 3.3

Sedunov, Yu. S. 1972

Fizika obrazovania zhidkokapelnoi fazy v atmosfere, Gidrometeoizdat, Leningrad, 207 pp.

A monograph on the "Physics of the Liquid Phase Formation in the Atmosphere" contains several chapters dedicated to the classical (quasisteady) approach to the droplet growth from a nucleus and to the heat exchange above the drop surface. The author discusses further the influence of the fluctuating fields on the droplet growth and formulates the axioms of the stochastic theory of condensation. A list of articles on the droplet growth investigations performed mainly in Russia is attached.

1.2 - 1.7 - 2.1 - 2.2 - 2.6

Semonin, R. G., and H. R. Plumlee 1966

Collision Efficiency of Charged Cloud Droplets in Electric Fields, J. Geophys. Res. 71, 4271-4277.

1.6 - 4.4

Serpolay, R. 1959

Expériences d' amélioration de la visibilité par temps de brouillard (Aeroport de Paris-Orly, Hiver 1958-1959) C.N.R.S. Obs. Puy de Dôme, 2, 43-63.

A detailed description of the experiments made at the airport Orly is presented. The author seeded supercooled fogs at Orly Airport. The liquid propane was diffused around the airport and some positive results were observed. More systematic measurements are needed.

5.12 - 6.1

Serpolay, R. 1960

L' atténuation des brouillards sur les aérodromes, Forces Aériennes Francaises, 167, 35-64.

The survey article has a wide documentation on this subject. The author discusses in general mainly the dispersion of supercooled fogs by liquid propane.

5.12

Serpolay, R. 1960

Sur l' utilisation des gaz chauds d' échappement de turboreacteurs pour dissiper les brouillards, Bull. C.N.R.S. Obs. Puy de Dome, 2, 47-52.

The author describes the experiments with the jet engine at the airport at Paris. The results are yet not conclusive and a modification is suggested for the continuation of the experiment at Orly.

5.1 - 5.2 - 5.5 - 6.1

Serpolay, R. 1961

Étude graphique de la modification de densité optique accompagnante la transformation d' un brouillard surfondu en brouillard de cristaux de glace, Bull. C.N.R.S. Obs. Puy de Dome, 2, 61-74.

The author calculated the precipitating effect of ice crystals on fog drops, and finally on the optical properties of the seeded fog. The examples are presented with some numerical values.

5.12 - 6.1

Serpolay, R. 1965

A Ground-Based Device for Dispersal of Supercooled Fogs Proc. Int. Conf. Cloud Phys., Met. Soc. Japan, Tokyo, 410-413, 12 ref.

5.12

Serpolay, R. 1969

Détermination expérimentale in situ de la temperature limite d' efficacité du dispositif de dispersion des brouillards surfondus installé sur l' aéroport d' Orly, J. Rech. Atmos. 2, 79-83.

Déscription of the experiments with liquid propane sprayers at the Orly Airport is presented. Apparently the threshold of an effective operation was close to 0°C.

5.12 - 6.1

Serpolay, R. and M. Andro 1972

Précipitation locale d' une nappe de brouillard par ensemencement a base de chlorure de sodium, J. Rech. Atmos. 6, 529-535.

A dense drizzle with the mean drop sizes of 200 µm was produced by seeding a fog of a layer thickness of 40 m with a grinded NaCl crystals (mean size between 5 -35 µm). The drizzle was observed 250 m leeward of the ground based system and lasted for 7 min. From 300 m before the seeding the visual range increased up to 1,100 m.

4.3 - 6.1

Serpolay, R. 1972

Projet d'expérimentation sur la modification des brouillards a toutes temperatures par voie physico-chimique. J. Rech. Atmos., 5, 185-191.

6.1

Severynse, G. T. 1963

Removal of Aerosol Particles from the Atmosphere by Growing Cloud Droplets, Geofis. pura e applic. 55, 151-163.

The diffusiophoretic influence on the catching of particles of Ni-Cr and heterogeneous natural aerosol and using Pollak photoelectric counter is described. The chamber was cylindrical r = 15.5 cm and 3.7 cm in depth. The bottom was covered by pure H_2O and at the top by $CaCl_2$ solution. The total volume was 2800 cm^3 volume. Using different separation of the walls the gradients of 180, 18 and 1.8 mm Hg cm^{-1} were attaigned. The general solution of the diffusion equation was found and used for calculating the concentration of aerosol particles.

4.1 - 5.9

Silverman, B. A. 1972

Warm Fog Dissipation in the United States, Paris, Joint Conference, Aeron. Met., May 1971, pp. 13, 13 ref.

5.1 - 5.6 - 6.1

Silverman, B. A. and A. I. Weinstein 1974

Weather and Climate Modification, N. Y. John Wiley & Sons, 355-383.

Dispersion of fogs is included in the monograph dealing in general with weather modification.

6.1

Sinclair, D. 1950 and 1963

Stability of Aerosols and Behavior of Aerosol Particles, Chapter 5 in the Handbook on Aerosols, Atomic Energy Commission, Washington, C.D., 64-76.

General problems related to the colloidal stability of aerosols are discussed such as: settling of airborne particles under gravity, Brownian motion, coagulation, movement of particles in an electric thermal gradient and acoustic field.

1.1 - 1.2 - 1.6 - 4.4 - 4.5

Simpson, J. H. 1949

The Meteorology of Chemical Warfare and Smoke, Porton Monograph. No. 9-400 (Perman. Records of Res. Development), Jan.

Classification of meteorological parameters and their importance for chemical warfare: Surface wind direction, surface wind speed, vert. grad. of air temperature, vert. gradient of wind speed, wind gustiness, surface temperature, relative humidity, air temperature. Different kinds of diffusional models, and confrontation with the experiments, is presented. The travel of gas over exceptionally rough surface and the theory of gravity spreading is discussed for specific cases of aircraft bombs etc. In detail is treated the evaporation from certain areas producing a persistent gas and the behavior of smoke screens.

2.1 to 2.6

Slinn, W. G. N. 1967

Precipitation Scavenging of Submicron Particles - A Theoretical Analysis, Proceedings of the USAEC Meteor. Inform. Meeting, Sept. 11-14, 1967, AECL-2787, Ed. C. A. Mawson, pp. 527-540, Chalk River, Ontario.

4.1 - 5.9

Slinn, W. G. N. 1968

The Convective Diffusion Equation for the Scavenging of Submicron Particles, Pacific Northwest Laboratory Annual Report for 1967, BNWL-715-3, pp. 171-183, Battelle-Northwest, Richland, Washington.

4.1 - 5.9

Slinn, W. G. N. and J. M. Hales 1971

A reevaluation of the Role of Thermophoresis as a Mechanism of *In- and Below- Cloud Scavenging*, J. Atmos. Sci., 28, 1465-1471.

The authors analyze the Brownian motion and phoretic transport to a suspended droplet. They conclude that the earlier calculation did not include the latent heat exchange on the drop surface. That explains some of the discrepancies between theory and experiment. Much importance is attributed to the thermophoretical forces.

4.1 - 5.9

Smith, Maynard (Editor) 1968

Recommended guide for the prediction of the dispersion of airborne effluents. Sponsored by Amer. Soc. Mech. Engin., Committee on Air Pollution Control, ASME, New York 85 pp.

3.1 - 3.2 - 3.3

Smith, T. B. and R. Wexler 1959

Un essai montrant que l' utilisation des gaz chauds d' échappement de moteur d' avion a réaction est practicable pour dissiper *les brouillards*, *Fin. Rep.* Part 1, Contr. No. AF 19 (604)-3492.

The experiments made at the Hanscom Field on 11 December 1958 have shown that there is a possibility of using jet engine heating for fog dispersion. The final effect, however, has to be checked in the future.

5.1 - 5.2 - 5.5 - 6.1

Smith, T. B., When-Wu Chien, and A. I. Weinstein 1970

Warm Fog Modification, AFCRL-70-0105, Altadena, Cal., Met. Res. Inc., Contract No. F19628-69-C-0021, Final Rep. 4°, pp. 52, 9 ref.

5.2 - 6.1

Smith, T. B. et al 1971

Warm Fog Modification Studies, AFCRL-71-0467, Altadena, Calif., Met. Res., Inc. Contract No. F19628-70-C-0069, Final Rep. 4 , pp. 98, 8 ref.

5.1 - 5.6 - 6.1

Smith, T. B., and D. M. Takeuchi 1973

Warm Fog Area Seeding Studies, AFCRL-TR-0437, Altadena, Cal. Met. Res. Inc., Contract No. F19628-72-C-0236, Final Rep., pp. 11.

4.3 - 5.1 - 6.1

Soloviev, A. D. 1965

The Dispersal of Fog with Positive Air Temperatures (In Russian) Trudy CAO, Moscow, 65, 9-29.

6.1

Soloviev, A. D. 1967

Fizicheskie osnovy metodov vozdeistvia na "teplye" tumany, Issledovania po fyzike oblakov i aktivnym vozdeistviam na pogodu, Gidrometeoizdat, Moskva, 209-218

Physical elements of the methods of affecting the "warm" fogs. Survey of all methods applied in the past including some criticism and economical effects.

6.1

Sood, S. K., and M. R. Jackson 1969

Scavenging of Atmospheric Particulate Matter by Falling Hydrometeors, Proc. 7th Int. Conf. CIN, Prague - Vienna, Sept. 1969, Academia, Prague, 229-303.

The scavenging efficiency of snow and ice crystals has been investigated in the cloud of μm spherical spores or of particulates of a fluorescent orange pigment. The scavenging of particulates was compared with a simple model which supports the conclusion of the experiments that snow and ice crystals have an efficiency of 1 to 4 percent in scavenging 1.0 to 3.4 μm particles from the atmosphere.

4.1 - 5.9

Sramek, L. 1966

Results of seeding experiments of supercooled fogs in cloud chambers by means of silver iodide atomized by means of pyrotechnic mixtures, J. Rech. Atmos. 2, 277-2.

The supercooled cloud was generated in a 200 ℓ cloud chamber and seeded with pyrotechnical AgI mixtures. Critical temperatures were -4°C to -9°C with the maximum occurrence at -6.5°C.

5.12

Splinter, W. E. 1968

Electrostatic Charging of Agricultural Sprays. Amer. Soc. Agr. Eng. Trans. 491-495.

1.6 - 4.4

Stewart, K. H. 1958

Proposals for Work on *Fog Dispersal by Hygroscopic Materials*, Met. Off. London, pp. 6.

4.3 - 5.6

Stewart, K. H. 1960

Recent Work on the Artificial Dispersal of Fog, Met. Magaz. (London, Met. Off.), 89, 311-319, 6 ref.

The critical survey of the work in Britain includes the FIDO system (1959-60 at Marlam 3 lines parallel of burners 900 yards long). Satisfactory clearance could be reached, however, hesitations with the continuation of the project. Also, surface-active chemicals were used (1955-58 - support of coagulation - no effects attributed to the spray were observed). Hygroscopic material (600 x 40 x 20 m space; $CaCl_2$), at Cardington, were used, however, no conclusions were reached.

4.2 - 4.3 - 5.1 - 5.6 - 6.1

Strauch, E. 1969

Warunki meteorologiczne rozraszania mgiel v Polsce PIHM, Prace, 92, 17-23.

Meteorological conditions of the fog dispersion in Poland. Macrocharacteristics of fogs in Poland are deduced for cloud (fog)dispersion trials. An outline of the possible program is mentioned.

2.1 - 2.7

Stratton, J. A. and H. G. Houghton 1931

A Theoretical Investigation of the Transmission of Light Through Fog, Physical Rev. 38: 159-165.

1.5 - 4.6

Strau. , W. 1966

Industrial Gas Cleaning: The Principles and Practice of the Control of Gaseous and Particulate Emissions

Pergamon Press, Inc. 44-01 21st Street Long Island City, New York 11101, 472 pp.

1.1 - 1.2 - 4.1 - 4.4 - 5.9 - 5.10 - 6.4

Stümke, H. 1964

Berücksichtigung vereinfachter Geländetypen bei der Berechnung der turbulenten Asbreitung von Schornsteingasen, Staub, 24.

A model of the propagation of pollutants from a chimney, in which an uneven terrain is assumed, is established. The exchange coefficient in the diffusion equation is kept constant.

3.1

Stümke, H. 1966

Untersuchungen zur turbulenten Ausbreitung von Schornsteingasen über nicht ebenem Gelände, Staub, 26.

Continuation of the work described in 1964. More general case of the propagation of pollutants from a chimney over an uneven terrain is considered.

3.1

Sumin, Iu. P. 1968

Metodika rasseiania pereokhlazhdennykh tumanov pirotechnicheskimi sostavami s iodidami serebra i svintsa, Trudy GGO, Leningrad 224, 37-42.

AgI, PbI_2 particles were used. The relationships are established between the rate of crystallization and wind speed, and between the time in which the crystallization zone reached its maximum and fog temperature. (The methodology of supercooled fog seeding with the pyrotechnical mixtures with the iodide of silver and lead.)

5.12

Sumin, Iu. P. 1969

Issledovania kristallizuiuschikh svoistv sernistoi medi pri vozdeistviakh na pereokhlazhdennye sloistoobraznye oblaka, Trudy GGO, Leningrad, 239, 21-35.

Airplane seeding with CuS (41 experiments) showed positive results when the temperature was $<-7°C$ and when the reagent was applied in excess of 400 g/km of aircraft path. In some cases was found the threshold temperature $-3°C$ and the consumption was 200-400 g of CuS per 1 km^3 of layer type cloud.

(Investigations on the crystallization capability of CuS for the supercooled layer-type clouds.)

5.12

Sutton, O. G. 1949

Atmospheric Turbulence, Methuen, London.

The author discusses in a condensed form the elements of the turbulent motion and the exchange of momentum, energy and mass in the atmospheric boundary layer. A short introduction into a statistical theory of turbulence is included. Finally, the author suggests formulas for practical calculation of diffusion and of the evaporation of water vapor from reservoirs.

2.5 - 2.6 - 3.1 - 3.2

Tag, P. M. 1974

A Numerical Simulation of Warm Fog Dissipation by Electrically Enhanced Coalescence, ENVPREDRSCHFAC, Techn. Pap. No. 3-74, Naval Postgrad. School, Monterey.

The main aim of this study was to test the enhanced coalescence mechanism due to the electric field charging in the Panama-Canal zone. The conclusions were: An electric field of 300 V cm^{-1} produces a negligible effect, 3,000 V cm^{-1} might increase the visibility. The visibility improvement factor was strongly dependent upon the initial fog liquid water content. Visibility improvement is primarily a result of an increased fall-out caused by drop-spectrum widening.

1.6 - 4.4 - 5.6

Sutton, O. G. 1953

Micrometeorology, McGraw-Hill, Inc., New York

A standard textbook dedicated to the problems related to the atmospheric boundary layer such as the termal stability, transport of momentum and heat in the atmosphere, turbulence and radiational transfer. Special attention is paid to the models of atmospheric diffusion under different conditions and to some application in the meteorology (evaporation) and environmental studies. Many references mainly on English contributions to this subject are attached.

2.5 - 2.6 - 3.1 - 3.2 - 3.4

Tag, P. M. 1977

Dissipation of fog using passive burner lines: Numerical sensitivity experiments, 6th Confer. on Planned and Inadvertent Weather Modification, Champain-Urbana, Ill., AMS, Boston, October, 1977, 180-183.

The dissipation of fog using a passive line or two lines of burners was simulated by a two dimentional model. The most important features were the use of a non-uniform stretched grid for the vertical coordinate and a variable eddy exchange coefficient including the buoyancy term. Calculations for "no-wind" and "crosswind" situations are discussed.

1.7 - 3.2 - 5.1 - 6.1

Taylor, G. I. 1917

The Formation of Fog and Mist, Quart. J. Roy. Meteor. Soc. 43, 241-268.

2.1 - 2.2 - 2.5 - 2.7

Tennekes, H. and J. D. Woods 1973

Coalescence in weakly turbulent cloud, Quart. J. Roy. Met. Soc. 99, 758-763.

4.1 - 5.9

Thudium, J. 1978

Water Uptake and Equilibrium Sizes of Aerosol Particles at High Relative Humidities: Their Dependence on the Composition of the Water-Soluble Material. Pageoph, 116, 130-148.

This author discusses at length the constants required to calculate the equilibrium water uptake of an aerosol particle. In particular attention is paid to the calculation of the osmotic coefficients required to calculate the exponential mass increase coefficient. Theoretical results for the osmotic coefficients agree very well with experimental data. These constants are then applied to aerosol particles to calculate their water uptake at relative humidities close to 100%.

4.3 - 4.6

Todd, C. J. 1967

A Method for Clearing Warm Fog to Allow Helicopter Support of Ground Forces, Norfolk, Va., Nav. Air-Sta., Navy Weath. Res. Facil., Tech. Pap. No. 2-67, 4°, pp. 53.

4.7 - 5.4 - 5.5

Todd, C. J. 1969

On the Design of Warm Fog Clearing Experiments Using Hygroscopic Treatments, Norfolk, Va., Nav. Air Sta., Navy Weath. Res. Facil. Tech. Pap. No. 20-69, 4°, pp. 6.

4.2 - 5.6

Toulcova, J., and J. Podzimek 1968

Contribution to the Question of the Catching of Aerosol Particles in the Wake of Falling Water Drops, J. Res. Atmos. 4, 89-95.

The study of the wake behind drop models falling in a tank filled with glycerol showed a significant change of the wake behind models at Re between 250 and 500. This can explain the strong change in collection efficiency of falling drops in this region found by Starr and Mason.

4.1 - 5.9

Tunicki, N. N., and I. V. Petrianov 1943

On the theory of aerosol filtration, (L. Ya. Karpov Institute of Physical Chemistry, Moscow, Aerosol Laboratory), J. Phys. Chem. (USSR), 17, 5-6, 408-413 (Transl. by E. R. Hope, Defense Sci. Inform. Ser., Defense Research Board, Canada, 1953).

The authors discuss in detail the coagulation of aerosols, effective particle radii and interaction between particles and internal filter. Energy of attraction is $1/r^{[illegible]}$. Formula is derived for interaction between spherical particle and cylindrical filament.

1.9 - 4.1

Tunicki, N. N. 1946

Diffusion processes under conditions of natural turbulence, J. Phys. Chem. (USSR) 20, 10, 1137-1141 (Transl. by E. R. Hope, Defense Sci. Inform. Ser., Defense Research Board, Ottawa, Canada).

Coagulation and evaporation of particles and drops in the atmosphere from the point of view of isotropic turbulence concept is outlined and the derivation of equations describing the droplet growth explained. The author considers also the heat exchange in the turbulent atmosphere.

2.6

Tverskoi, N. P. 1960

Effects of Frequency and Intensity of Acoustic Oscillations on the Rate of Dispersal of Water Fog, Leningrad, Trudy GGO, Rep. 104, 85-94, 5 ref.

4.5

Tyldesley, J. B. 1965

The Solution of Atmospheric Diffusion Equations My Electrical Analogue Methods, Sci. Paper #22, Met. 0.770, (Bracknell).

3.1 - 3.2

U.S.A.F., Cambridge, Res. Lab., Bedford 1968

Use of Helicopters to Dissipate Warm Fog, Met. Lab. U. S. Air Force, Office of Aerospace Research, Research Review 7:15.

The position of the helicopter was 100 ft. above the cloud or fog. The relative humidity of the dryer air should be 90% or less. If the air above the cloud or fog layer has a higher humidity, the mixing might actually deepen the fog.

5.4 - 5.5 - 6.1

U.S.A.F., Cambridge, Res. Lab., Bedford 1969

Helicopter Technique for Clearing Warm Fog and Clouds, Met. Lab. U. S. Air Force, Office of Aerospace Research, Res. Review 8: 10.

Warm fog layers 200 ft. thick were repeatedly cleared using he icopters.

5.4 - 5.5 - 6.1

U. S. NASA 1969

Progress of NASA Research on Warm Fog properties and Modification Concepts, Proceedings of a symposium, Wash. D.C. Feb. 6, 1969, Spec. Public. No. 212.

The main objectives were to discuss the results of recent warm fog seeding experiments at the Chemung County Airport, Elmira, N. Y., (Cornell Aeron. Lab.) and other related subjects.

6.1

VAL Fog Clearance 1966

Aeroplane, London III, No. 2843, p. 23.

5.1 - 5.12 - 6.1

Vadell, M. 1961

Essais de dissipation de brouillards non chargés par projection de brouillards électrisés composés de quantités égales des gouttes chargées positivement et de gouttes chargées négativement, Bull. C.N.R.S. Obs. Puy de Dôme, 1, 41-45.

The author made experiments which led to the conclusion that the effect of bipolarly charged drops on the fog dispersion in a cage is less expressed than unipolarly charged.

4.4 - 5.8

Van De Vyver 1901

Action de l'électricité sur le brouillard, Bruxelles, Bul. Acad. Roy., 486-493.
and
Nature, Paris, 30 (1902), 118-120
Cosmos, Paris, 45 (1902), 595-598

4.4 - 5.8

Van Valin, Ch. C., and P. A. Alee 1970

Silanes as Cloud Stabilizers, U. S. Atm. Physics and Chemistry Lab., Boulder, Tech. Rep. ERL 105-APCL 6, April, also in Nat. Conf. on Weather Modif. Santa Barbara, April 6-9.

Silanes (alkylchlorosilicon compounds) are effective in stabilizing cloud droplets against evaporation due to the silicon polymer film on the surface of the drops. These substances were also found to be effective in preventing the nucleation of supercooled water drops.

4.3

Vialtsev, V. V. 1969

Rasseianie vodnogo tumana zvukovymi kolebaniami, Vysokogorn. Geofizich. Inst., Nalchik, Trudy 13, 123-131.

The investigations were made in a chamber of 500 m^3 at low frequency (sonic) acoustic vibrations. The speed of dispersion increased under favorable frequencies 15 - 20 x. (Dispersion of water fog by acoustic waves.)

4.5 - 5.7

Verger - Deloncle, M. 1966

Application des méthodes radiométriques à la physique des nuages, J. Rech. Atmos. 2, 39-46.

The author surveys the wide field of the application of the measurements of propagation of electromagnetic waves to the investigation of clouds and vice versa, how the clouds influence the propagation of light in infrared domain. Many quotations are attached.

1.5

Volkovitskii, O. A., L. I. Ermoshina, and L. N. Pavlova 1967

Predvaritelnye dannye ob "adiabaticheskykh" tumanakh v bolshoi kamere, AKN SSSR, Inst. Prikl. Geofiziki, Trudy 7, 49-58

Results of preliminary experimental investigations on the creation of fog in a chamber during adiabatic expansions of air are presented. The equations for calculating the drop temperature and the course of humidity are presented. The dispersion of fog in the chamber occurred unevenly with height. In the upper part of the chamber fog dispersed more rapidly. (Preliminary results of "adiabatic" fogs in a large chamber.)

4.1 - 4.2

Wall, F. T. 1945

Preparation and properties of aerosols, U. S. Dep. of Commerce, Publ. Report 6208.

1.1 - 1.2 - 1.4

Walker, E. G., and D. A. Fox 1942-1946

The Dispersal of Fog From Airfield Runways, Record of the Work of Tech. Branch F of the Petrol. Warfare Dept., Min. of Supply, London, 321 pp.

6.1

Wallington, C. E. 1968

Numerical Solution of Atmospheric Diffusion Equations, Sci. Paper #28, Met. 0.806, (Bracknell).

3.1

Walter, G. 1904

Nezelzerstreuung durch Elektrizität, Umschau, Frankfurt a. M. 8, 1003-1006.

1.6 - 4.4 - 5.8

Washington, Air Weather Service 1968

Final Report on the Air Weather Service, FY 1968 Weather Modification Program. Volume I., Projects: Warm Fog, Cold Fog III, Cold Wand, Cold Horn, and Cold Fan. Tech. Rep. 209, Washington, la 8°, pp. 58.

6.1

Wedding, J. B. and J. J. Stukel 1974

Operational Limits of Vibrating Orifice Aerosol Generator, Envir. Sci. and Technol. 8, 456-457.

4.1

Watts, R. G. 1971

Relaxation time and steady evaporation rate of freely falling raindrops, J. Atm. Sci. 28: 219-225.

The solution of the behavior of evaporating and falling drop is presented. The relaxation time for different sizes of drops and humidities as well as a given temperature are τ = 20 sec for d = 10^{-1}cm and τ = 0.3 sec. for d = 10^{-2}cm at 80% RH and T = 20°C. The steady state evaporation of falling drops is calculated for small Stokes numbers.

4.1

Weick, F. E. 1952

Gauge Dispersal of Agricultural Materials from Experimental Airplane, Texas Engin. Exper. Sta. News (Texas Agr. and Mech. Inst., College Station, Texas), 3, 2, 8-13

Dispersion equipment for dusts, fertilizers, seeds and sprays by aircraft is being developed. Hopper for dust can be located in fuselage. Samples in the field were taken by means of balances. Drops were collected on paper moistened with dyed water.

3.1

Weickmann, H. K. 1963

A realistic appraisal of weather control, Z. A. M. P. 14, 528-43.

4.3 - 5.3 - 5.5 - 5.6 - 6.1

Weickmann, H. K. 1968

Program on Weather Modification of the Environmental Science Services Administration (ESSA), Pt. I, Cloud dissipation, Idöjárás, Budapest, 72: 65-78.

The survey of the present activity on this field including the dissipation of clouds using condensation nuclei is presented. The formulation of a "Seedability Index" is attempted and results of several programs mentioned.

6.1

Weinstein, A. I. 1973

Thermal Warm Fog Dissipation - Heat Requirements and Projected Utilization of a System for Travis AFB, California, Air Force Systems Command, U. S. Air Force, June, AFCRL-TR-73-0367

5.1 - 5.5

Weinstein, A. I., and B. A. Silverman 1973

A Numerical Analysis of Source Practical Aspects of Airborne Area Seeding for Warm Fog Dispersal of Airports, J. Appl. Met. 12, 771-780

Two dimensional Eulerian model of warm fog dispersal by airborne particle seeding is deduced for testing the area particle seeding at airports. In general transport equations are used for water vapor density, three classes of fog liquid water content, five classes of hygroacopic particles, and "hygroscopic" liquid water content. Turbulence and wind shear reduce the effectiveness of a single-line seedings. For typical fog 80,000 lb. hr. of urea costing $40,000 per hr. are needed to keep the visibility above 1/2 mi.

4.3 - 5.6 - 6.1

Weinstein, A. I. 1974

Projected Utilization of Warm Fog Dispersal Systems at Several Major Airports, J. Appl. Met. 13, 788-795.

5.1 - 5.2 - 6.2

Wells, W. C., G. Gal, and M. W. Munn 1976

Aerosol Distributions in Maritime Air and Predicted Scattering Coefficients in the Infrared, LMSC/D457849, Palo Alto, June.

An empirically developed aerosol size distribution function has been applied for the calculation of infrared extinction coefficients as a function of sea level wind, humidity, and altitude. The size distribution function compared with other data measured over the ocean showed a reasonably good agreement. The compared data involved only coastal conditions.

1.5 - 4.6

Whitby, K. T. 1950

Determination of particle size distribution - Apparatus and Techniques for Flour Mill Dust, Univ. of Minnesota Inst. of Technol. Engin. Exper. Sta. Bul. No. 32, 35 p.

1.2

White, H. J. 1955

Modern Electrical Precipitation, Ind. Eng. Chem. 47, 932-938.

1.6 - 4.4

White, H. J. 1951

Particle Charging in Electrostatic Precipitation, Trans. Amer. Inst. Electr. Engin. 70: 1186-1191.

Electrical field near charged and uncharged spheres is studied. For specific cases the gas-ion current and charging of particulates is calculated.

1.6 - 4.4

White, W. C. et al 1969

Project Tule Fog; An Investigation of Warm Fog Dispersal Using Hygroscopic Solutions, U. S. Naval Weapons Center, China Lake, Calif. NWC Technical Publ. 4766.

Hygroscopic solutions dispersed from an aircraft were tested for their warm fog dispersal potential over the Naval Air Station, *Lemoore, Calif.*, in the San Joaquin Valley. Of 4 tests only one was positive (200 gal/min).

4.3 - 5.6 - 6.1

White, H. J. 1963

Industrial Electrostatic Precipitation, Addison-Wesley Publishing Company, Inc., Reading, Mass., 376 pp.

A monograph dedicated to the physical principles of charging small particulates and of electrostatic precipitation. Many useful applications in the industry with the calculation of the efficiency of the suggested arrangements are mentioned. Very extended list of references mainly from western countries is attached.

4.4

Whytlow-Gray, R., W. Cawood, and H. S. Patterson 1936

A Sedimentation method of finding the number of particles in smokes, Trans. Faraday Soc. (Engl.), 32, 1055-1059.

Apparatus for preparing collection slides of smoke particles is described. A definite, small volume of smoke is captured in a circular, flat chamber formed in a brass plate between two glass plates, and is allowed to sediment on the lower glass plate; the settled particles can be observed and counted by microscope. Results are given of tests using cadmium oxide smoke.

1.2

Widell, T. 1936

Zur Berechnung der Fallgeschwindigkeit von Stäuben, VDI-Zeitschr. 80, 1497-1498

VDI-Z., Vol. 80, no. 50, 1497-1498.

1.8

Wigand, A. 1932

Experimentelle and theoretische Studium zur Koagulation inhomogenen Nebels, Ann. Hydr., 60, 25-28.

1.1 - 1.2 - 4.1

Wigand, A. 1926

Ladungsmessungen an natürlichen Nebel, Z. f. Geophysik, 2, 331
and
Met. Z. 43, 481-482

1.6

Wigand, A., and E. Frankenberger 1930

Uber Beständigkeit und Koagulation von Nebel und Wolken, Physik Z., Leipzig, 31, 204-215.

1.1 - 1.2 - 4.1

Wigand, A., and E. Frankenberger 1931

Die elelatrostatische Stabilisierung von Nebel und Wolken und die Niederschlagsbildung. Ann. Hydr., 59, 353-363, 398-403.

1.6 - 4.5

Winkel, A. 1944

Das Messen in der Staubtechnik, VDI-Zeitschr., 88, 296-297

Abstracts of paper read at the Symposium (Oct. 1943) of the VDI Subcommittee on Measuring Methods in Dust Technology; measurements with light and electron microscope, photoelectric and sedimentation methods are mainly discussed.

1.1 - 1.2 - 1.10 - 1.11

Wise, J. L. 1975

Operational Cold Fog Dissipation in Alaska, Proc. Alaska Sci. Conf. 24th Univ. of Alaska, Aug. 15-17, 1973. Climate of the Arctic, Fairbanks, Geophys. Institute, p. 323-326.

The author describes the history of the work at the Elmendorf AFB in Alaska and the physical basis of the interference into the supercooled fogs with propane. Also experiments with dry ice dispersed from balloons are described. Similar techniques (with CO_2) were used for aircraft dispersion (WC-130). Propane system had several advantages.

5.12

Witzmann, H. 1944

Photoelektrische Methoden zur Teilchengrössebestimmung disperser Systeme, VDI-Zeitschr. 88, 266-267
Paper at Symp. (1943), VDI Subcomm. on Measuring Methods of Dust Technology, Abstr. in VDI-Z, Vol. 88, 266-267.

The author shows that the intensity of dispersed light is proportional to the third power of the particle size in the range of fine aerosols, to the second power for larger dust particles, and to the first power for particles above 50 μm. Discussion of photoelectric sedimentation analysis is done and the author describes his own method in which dust particles are kept in suspension.

1.10

WMO 1972

Dispersion and Forecasting of Air Pollution, Tech. Note No. 121, WMO-No. 319, Geneva, 116 pp.

The WMO survey monograph contains chapter: Plume rise, transport and dispersion in non-urban environments and in urban environments and forecasting for air pollution applications. In the Appendix is a very useful summary on the atmospheric diffusion investigation in the USSR.

2.5 - 2.6 - 3.1 - 3.2

Woods, J. E., J. C. Drake and P. Goldsmith 1972

Coalescence in a turbulent cloud, Quart. J. Roy. Met. Soc. 98, 135-149.

4.1 - 5.9

Wright-Patterson Air Force Base, Ohio, Air Force Systems Command, Foreign Technol. Division 1968

Polish Ultrasonic Device for Fog Dispersion, Transl. from Tech. Warsaw, No. 7, p. 427.

Principle of the suggested method is to use two loudspeakers located on two ships. The loudspeakers are connected together and emit signals with the amplitude and frequency making maximum effect on fog droplet coagulation. Large drops will further grow by collecting the fog droplets and will fall out.

4.5 - 5.7 - 6.1

Wright, T. L. and R. S. Clark 1973

Field Evaluation of an Electrogasdynamic Fog Dispersal Concept, Part II. Washington, FAA, Syst. Res. Dev. Serv. Rep. No. FAA-RD-73-33, pp. 80-134 8 ref.

4.4 - 5.8 - 6.1

Wright, T. L. and R. S. Clark 1973

Warm Fog Dispersal Tests with Glycerine in the Panama Canal Zone, Part II. Testing and Evaluation of Glycerine in Foggy Cloud V. Washington, FAA, Syst. Res. Dev. Serv. Rep. No. FAA-RD-73-21, Grant 2, pp. 19 8 ref.

4.3 - 6.1

Yue, P., and J. Podzimek 1976

New Technique for Studying the Deposition of Droplets on the Ice Crystal Surface, Preprints Int. Conf. on Cloud Physics, Boulder, AMS, Boston, July, 180-183.

The authors used a simple technique for investigating the catching efficiency of simulated ice crystals in a small wind tunnel. Salt solution drops transported in the air flow left circular spots in a sensitized gelatin sheet which covered the models. The patern of drops deposited on a crystal model of a specific shape was related to the Reynolds and Stokes number.

4.1 - 5.9

Zakharova, M. and Yu. S. Sedunov 1976

Chislennoie modelirovanie vozdeistvia iskusstvennymi iadrami kondensatsii na protsess razvitia radiatsionnogo tumana, Meteor. i Gidrolog., Nov. 3-8.

(Numerical simulation of a radiation fog evolution process after seeding it with artificial condensation nuclei.)

An attempt is presented to describe the microstructural change in a radiation fog due to the seeding by hygroscopic nuclei. Due to the seeding the condensational process is supported and a decrease in drop size and simultaneous increase in water content of the fog was found. The visibility in the fog layer decreased approximately three times.

4.3 - 5.6

Zarca, S., and C. Capuz 1969

Unele rezultate ale experimentarii in labor a metodei acustice de disipare a cetii, Culagerea de Lucrari, Inst. Meteor. Rumania, Bucharest.

Laboratory experiments were made at the Meteorological Institute in Bucharest of fog dissipation by an acoustic field. Optimal frequencies for the tests are 5,000 - 15,000 Hz. (Some results of the laboratory experiments with the acoustic method to disperse the fog.)

4.5 - 5.7

Zdunkowski, W. G. and B. C. Nielsen 1969

A Preliminary Prediction Analysis of Radiation Fog, Pure and Appl. Geophys. 75, 278-299.

2.1 - 2.2 - 2.5 - 2.7

Zerea, S. 1962

Contributions to the Study of Fog Dispersion by Means of Gasjets. Culagerea de Lucrari, Insti. Met. Centr. Bucharest, Perannul 1960, 213-231. (In Rumanian with English Abstract)

5.2 - 5.5 - 6.1

Zilitinkevich, S. S. 1966

The Effect of the Dissipation of Fog by Dynamic Means, Leningrad, Trudy GGO, Leningrad, 187, 217-220.

An analysis of the horizontal air advection into a fog is made with the aim to interfere into the fog microstructure. The author concludes that a forced dry air motions can considerably contribute to the droplet evaporation and finally to fog dispersion above an area corresponding to the airport's runway.

4.7

Zilitinkevich, S. S. 1967

Dinamicheskii metod rasseiania tumana, Issledovanie po fizike oblakov i aktivnym vozdeistviam na pogodu, Gidrometeoizdat, Moskva, 227-232

(Dynamic method of fog dispersion.)

4.7 - 5.5

Zinner, E. 1917

Bildung einer Haufenwolke über einer Rauchwolke, Meteor. Zeitschr. 34, 264-265.

The observations and photographs show clearly that in the highly polluted cloud above the village fire originated a cumulus type cloud through convection and dissipated through abscrption of solar radiation.

S.3 - S.4

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